A Study of Riverine Plant Communities in Tasmania, with Especial Reference to Central East Coast Rivers

by

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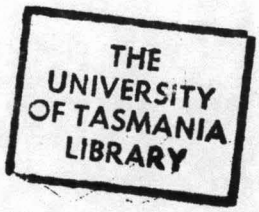

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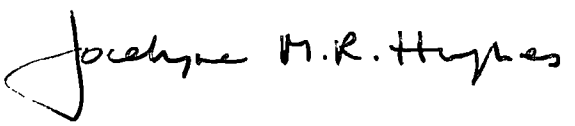

J.M.R. Hughes

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ABSTRACT

A study of riverine plant communities in Tasmania, with especial reference to central east coast rivers

Plants growing in and along rivers have received little ecological and conceptual attention. Current deterministic and stochastic lotic community concepts are examined, along with concepts in plant ecology (individualistic and organismic concepts, plant succession, disturbance, physiographic plant geography) and their application to lotic plant communities. This theoretical framework is used to investigate the spatial and temporal variability of riverine plant communities in the island state of Tasmania and to establish relationships between this variation and major environmental factors.

In order to establish a suitable strategy with which to sample lotic plant communities, levels of hydrological and chemical disturbance were investigated along Tasmanian rivers. Annual flow records, monthly flow records, peak and low flow records were used to derive an objective hydrological regionalization for 77 rivers. Four contiguous groups were determined with the south east region of the island exhibiting hydrological regimes similar to those of the drier areas of mainland Australia. The wettest areas, in the south and west, have regimes with no analogue elsewhere within mainland Australia. The water chemistry of Tasmanian rivers displays similar contrasts, though variability tends to be greater temporally than spatially.

To provide data on aquatic vegetation dynamics following disturbance, 14 permanent plots were set up along the Swan and Apsley Rivers, eastern Tasmania, and monitored over a 28 month period. Records were made of plant species composition and cover, as well as measurements of water chemistry and hydrology.

Between-site (spatial) as well as within-site (temporal) variability of aquatic plant communities along the study rivers is pronounced. Species cover, diversity, richness and turnover show significant changes after high and low hydrological events, but less so between seasons. Spatial variability is highly influenced by the water chemistry, and within the brackish and freshwater components of the rivers, hydrological variables are the major influence. This evidence on site-specific succession does not support an organismic interpretation, and lotic aquatic plant communities appear to have a low resistance to disturbance and low resilience after disturbance. Disturbance tends to favour opportunistic species which recover rapidly vegetatively, and tends to allow the coexistence of a relatively high number of species which display polydominance.

To provide data on the spatial distributions of riverine communities, riparian and aquatic plants were intensively sampled along the length and breadth of the Swan and Apsley Rivers. Riparian plant communities vary longitudinally along the river in response to geology and gradient index (which combines altitude and distance from the drainage divide). Lateral variations away from the river are a response to a flooding gradient and substratum stability. Dense overhanging riparian vegetation excludes growth of aquatic species, though this situation is nullified where the canopy has been cleared for agriculture or for roads.

A geographical survey of aquatic plants along rivers in Tasmania indicates that the plant communities are predominantly influenced by filterable residue and colour and to a lesser extent by substratum and hydrology.

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Chapter 1

Introduction

1.1 Preamble

Stream ecology has been considered by some to be conceptually immature (Hynes 1970, Barnes and Minshall 1983a). However, various deterministic concepts specific to lotic environments have been put forward in the last decade (e.g. the River Continuum Concept), while recent work has shown a tendency towards a more individualistic, stochastic approach (Lake 1985, Grossman et al. 1985, Peckarsky 1983). This chapter summarizes the body of specifically lotic ecological theory, and evaluates the relevance of general ecological theory to lotic plant communities. This discussion is used as the basis for the development of questions relevant to the plant geography of Tasmanian riverine environments.

1.2 Deterministic vs. stochastic community concepts

The term stochastic refers to scientific explanations that contain some probabilistic elements, and the term deterministic to those explanations containing no elements that are probabilistic (Glasser and Wiegert 1983). Thus a deterministic community is conceived as a collection of species in equilibrium, with a consequent predictable structure, and a stochastic community is conceived as being a collection of species in a non-equilibrial state which changes with spatial and temporal environmental change. Deterministic explanations are effectively without alternatives and stochastic explanations are probabilistic, within which all alternatives are equally probable. Thus, deterministic and stochastic communities are well separated along a probability continuum (Glasser and Wiegert 1983).

During the last decade, much stream research has been synecological and holistic. There are four main areas in which developments in stream ecosystem theory have taken place. Three of these areas are relevant to the spatial and temporal distributions of plants along rivers. The fourth area of development, that of material cycling in open systems (Elwood et al 1983), will not be considered in this discussion.

Firstly, there has been the development of the River Continuum Concept (RCC, Vannote et al. 1980). The entire fluvial system is regarded as a continuously intergrading series of physical gradients and associated biotic adjustments. Streams are seen as longitudinally linked systems in which ecosystem-level processes in downstream areas are linked to those in upstream areas. Biological adjustments are evident in the changing balance of production and decomposition, and in changes of species composition. Changes in community composition are expressed as a downstream succession of 'functional groups'. Leaf material deposited in the headwater section of a stream is subjected to the action of 'shredders', and plant material produced in the stream is utilized by 'grazers'. The pattern is that of a continuum, where course particulate organic matter (CPOM) is progressively reduced to fine particulate organic matter (FPOM) by the successive actions of the 'litter processors'. The RCC provides deterministic generalizations concerning the magnitude and variation through time and space of organic matter supply, the structure of invertebrate communities, and resource partitioning along the length of a river. Thus, corresponding to changes in food resources (e.g. macrophyte detritus, riparian detritus, algae), the fauna is similarly structured in a predictable and orderly fashion, with the highest faunal (and floral) diversity being in the mid reaches of streams. Cushing et al. (1983) stated that 'streams are best viewed as gradients, or continua, and that classification systems which separate discrete reaches are

of little ecological value.'

The validity of the RCC, particularly in its application to Australian and New Zealand streams has been questioned by Winterbourn et al. (1981), Winterbourn (1982), Barmuta and Lake (1982), Lake (1982, 1985) and Lake et al. (1985a). These objections are based on the problems inherent in imposing a deterministic model upon a (possibly) loosely-structured stochastic system. Additionally, many streams in Australia and New Zealand are physically (McMahon 1982a) and biologically (Lake et al. 1985a) unlike those of the deciduous forested regions of North America, where the concept originated. The environmental features that distinguish Australian streams from northern hemisphere streams are: a) low and variable discharges; b) summer inputs of allochthonous detritus; c) greater quantities of woody detritus (Lake et al. 1985a, Bunn 1986).

The use of the RCC as a framework within which to examine spatial and temporal distributions of stream vascular plants has obvious limitations. The concept was developed by zoologists to examine communities of stream fauna, and in particular, functional groups of stream macroinvertebrates. Stream vegetation has thus tended to assume a deterministic role for explaining macroinvertebrate distributions (Gregg and Rose 1985, Rabe and Gibson 1984). From the discussion so far it is possible to address several questions concerning the distributions of plants in streams:

* Is the diversity and richness of riverine plants highest in the mid reaches of streams where there is (possibly) maximisation of environmental variability? (Chapter 4)

* Are plant species distributed in a continually varying fashion downstream in response to a 'continuous' or 'intergrading' longitudinal gradient of environments? (Chapter 4)

The second area of theoretical development in stream ecology has been articulated in the work of Cummins et al. (1983, 1984) and Cummins (1986), who, in their papers on stream ecosystem theory, argue that aquatic and riparian vegetation also exert a major control over biotic associations in lotic environments. This control is exerted through physical channel influences (e.g. shading, woody debris) and the nature of organic inputs from in-stream plant growth (autochthonous) and from outside the wetted channel (allochthonous). Another question emerges in relation to plant distributions:

* Is the distribution and species composition of aquatic vascular plant communities influenced by the nature of the riparian communities and the terrestrial setting of the stream? (Chapter 4)

The third area of theoretical development in stream ecology has been in the area of biotic interactions within stream communities (McAuliffe 1983, 1984, Barnes and Minshall 1983b). The importance of biotic interactions has been disputed by the adversaries of the RCC, who, perhaps justifiably, suggest that streams are unpredictable and variable, and thus do not allow the application of the more conventional community ecology concepts. Grossman et al. (1982) and Grossman et al. (1985) demonstrate how a stream fish assemblage is a stochastically rather than a deterministically organised one. Thus, unpredictable environmental disturbances have greater effects than interactive processes such as competition and grazing (Ross et al 1985, Canton et al. 1984). Other studies (e.g. Bunn et al. 1986, Lake et al. 1985a, 1985b, Peckarsky 1983) suggest that lotic invertebrate communities may be similarly disorganised. It seems, however, that the stochastic nature of river communities is becoming evident to the proponents of the RCC (Statzner and Higler 1985). Minshall et al. (1985) state that '...while stream communities are not strictly deterministic, neither are they a hodge podge of

organisms resulting solely from stochastic events....there is a high degree of predictability (and hence opportunity for determinism) embedded in the apparent stochasticity of streams.' This rapid evolution of ideas in the last five years, from an essentially deterministic stance to the incorporation of individualistic and stochastic ideas, is resulting in the emergence of a more realistic set of testable hypotheses.

Haslam (1978) discussed the distribution of aquatic plant communities along rivers in the United Kingdom. She concluded that 'superimposed on these general (longitudinal) trends there may be marked variations in any one stretch of the stream as the result of changes in topography, geology, human interference etc.' (page 174). Haslam also discussed the effects of stormflows and states that 'plant patterns within one site may be much affected by storm or drought flows, as individual small populations are washed away and then replaced by other species, or the space they occupied left bare' (page 84).

Haslam's monograph preceded the recent bulk of lotic literature, but it can be concluded that she regarded the macrophytic communities along rivers to be distributed in response to both stochastic and deterministic processes. Between periods of disturbance or physical variation (stochastic events) there may be sufficient time to permit the establishment and maintenance of equilibrium conditions. From these studies a fourth question may be asked:

* Are deterministic physico-chemical processes a major influence on the distribution of plant communities along the length of a river? (Chapter 4)

1.3 Concepts in plant ecology and their application to plant communities

1.3.1 Individualistic vs. organismic concepts

The organismic community concept derived from the work of Clements (1935), assumes that the plant community is made up of strongly interacting individuals and species (Richardson 1980). The opposite concept, that of the individualistic community, was formulated by Gleason (1926). The community is seen as a collection of species that happen to exist together through converging accidents of space, time and similar environmental needs (Richardson 1980).

Physically controlled communities (e.g. those in unstable or unpredictable environments) are likely to be individualistic in their composition because they are composed of r-selected species whose reproductive and dispersal characteristics suit them to disturbances (Sanders 1968, MacArthur and Wilson 1967). Biologically accomodated species are K-selected and are the result of selection for competition-reducing adaptations and for mutualistic interdependencies in stable areas.

Mutualism is possible to a far greater degree within the consumer and decomposer segments of a stream community (Cummins 1974, Cummins and Klug 1979), than within the plant segment, because nutritional specialization has been achieved by animals and decomposers (Richardson 1980). Coexisting animal species, even in the same trophic category, often use completely different foods (Cummins and Klug 1979, Richardson 1980). If they can minimize competition and differences in resource uses, then they can (theoretically) achieve an organismic integration beyond that for plants. There is, however, an extensive body of literature stressing the idea that faunal stream communities are primarily determined by the nature and variation of physico-chemical factors rather than the strength of biological interactions (see Hynes 1970, Layher and Maughan 1985), and that individual lotic species have individual

requirements (eg Orth and Maughan 1983, Reice 1980).

Evidence supporting organismic or individualistic concepts for lotic plant communities is sparse. Lentic plant communities have been studied far more extensively, and provide useful insights into lotic systems. For example, Keddy (1984) examined plant zonation on a lake shore in Nova Scotia, to examine which of two contrasting approaches was more appropriate in understanding the coexistence of plant species. The first approach emphasizes the differential use of physico-chemical factors as a mechanism for avoiding competitive exclusion. The other approach emphasizes physical disturbance and temporary coexistence. The results from this study show that although water depth and exposure influence the distributions of lake shore species, disturbance from waves and fluctuating water levels appears to play an important part in the variation in the number of plant species on a lake shore.

Similarly, Raup (1975) found no sequential zones or communities around the shores of Lake Athabasca, but a completely individualistic association of species. The fluctuating mix of species was the result of recurrent disturbance, and there were no predictable relations between species and microsite. Raup showed that the most specialized plants (helophytes and aquatics) were the least versatile species, which represented a compromise between specialization and flexibility in disturbance response.

This review leads to a fifth question:

* Can lotic plant communities be regarded as individualistic plant assemblages, that are the result of recurrent disturbances? (Chapter 3)

1.3.2 Plant succession

Individualistic-organismic concepts are intrinsic to the temporal (and sometimes spatial) concept of succession. The Gleasonian, individualistic view of succession is represented by Horn (1974), Drury and Nisbet (1973), Connell and Slatyer (1977), Noble and Slatyer (1977, 1980), Glenn-Lewin (1980), Peet and Christiansen (1980). Here succession is viewed as a consequence of adaptation and natural selection at the level of the individual, resulting in a probabilistic process. The Clementsian, organismic successional model is deterministic, and assumes that following a disturbance the community gradually resumes the structure and composition of the surrounding undisturbed area by an orderly and predictable series of species replacements.

In some situations, typically associated with primary succession on, for example, glacial forefields (Cooper 1926), or with secondary succession following the abandonment of cultivation (Billings 1938), classical concepts appear to be valid. In many other situations where disturbances of a more natural type occur at reasonably regular intervals and do not completely remove resident species, the classical concepts have little applicability (Connell and Slatyer 1977, Purdie and Slatyer 1976, Noble and Slatyer 1980, Drury and Nisbet 1973).

In extreme environments species-species interactions tend to be reduced compared with the interaction between a species and the physico-chemical environment (Noble and Slatyer 1977). In rivers and streams, where floods can be an important recurrent event, classical concepts of secondary vegetation succession may be inapplicable. Classical concepts would treat floods as an externally induced aberration which causes a regression (or flood induced disclimax) in an otherwise progressive successional sequence of river vegetation (whatever that sequence might be). For lentic environments, Ricklefs (1980) used the term

'transient climax' for communities developing in temporary ponds, and Van der Valk (1981) interpreted vegetation change of prairie glacial marshes as a cycle of phases.

This view of succession was adopted by Vannotte et al. (1980) who stated that the temporal change of the biological system of a stream 'becomes the slow process of evolutionary drift' and the community 'gains and loses species in response to low probability cataclysmic events and in response to slow processes of channel development.' As a result of this, succession in stream ecosystems is absent and these systems can be viewed in a time-independent fashion. However, if disturbance events are accepted as a factor that causes gains or losses of species, it is expected that biological communities in streams are re-established afterwards by means of succession (Fisher 1983, Statzner and Higler 1985).

A scheme for predicting major shifts in species composition in plant communities subject to recurrent disturbance has been developed (Noble and Slatyer 1977, 1980). It is entirely based on unique life history characteristics of individual plant species, or 'vital attributes' to determine patterns of succession at a particular site. This individualistic scheme has advantages over classical autogenic succession, because each sequence generates its own shift in community composition through the vital attributes of the species. Although this work was derived to deal mainly with terrestrial communities dominated by higher plants, it is applicable to plants in lotic environments. Thus work by Mitchell and Rogers (1985) may be used in such a scheme as it reviews the adaptations and responses (or 'vital attributes') of aquatic plants to seasonal and aseasonal components in the environment in the Southern Hemisphere. This view of individual life histories is also considered by Sousa (1980) for succession on intertidal boulders, and is implied by Gopal (1986) for shallow and temporary fresh water bodies.

There has been little specific research into secondary succession in riverine plant communites, but two studies do demonstrate within and between-season changes. Schloesser et al. (1985) examined the biomass of submerged macrophyte communites in the St. Clair-Detroit river system (April to November 1978) and found three seasonal growth patterns: one dominant taxon grew alone; co-dominant taxa grew sympatrically without species succession; co-dominant taxa grew sympatrically with species succession. These differences were attributed to competition, life-cycle differences and overwintering plant material. Discharge fluctuations were not considered in the study. Dawson et al. (1978) attribute between-season changes in plant cover of a Rorippa-Ranunculus complex in a Dorset chalk stream to a 'cycloclimax', where plant generations are timed to environmental fluctuations. In this case the environmental fluctuations are regular changes in the flow cycle which exert a profound influence on the vegetation. They state that 'provided it is possible to show that adaptive mechanisms do exist and that communities are stable, the vegetation of the rivers, both macrophyte and plankton, can be therefore regarded as a climax pattern array.' However, in Australia, where river discharges are highly variable and where floods are an order of magnitude larger than they are for world average streams (McMahon 1982), lotic plant communities may react very differently. Two additional questions emerge:

* Do environmentally adapted lotic species reestablish themselves after a disturbance by means of succession? (Chapter 3)

* Can changes in species composition or cover (succession) in lotic plant communities be predicted from life history characteristics of individual plant species? (Chapter 3)

1.3.3 Disturbance

Grime (1977) recognised three factors as causal to vegetation changes: disturbance, stress and competition. These have been implied during the course of this discussion, but central to the initiation of change and succession in lotic vegetation communities is the role of disturbance (Butcher 1933, Sculthorpe 1967, Dawson 1979, Wiegleb 1984). Natural disturbances have been traditionally defined in terms of major catastrophic events originating in the physical environment e.g. fires, floods, but this view is very limiting as disturbance processes belong in a wider context (White 1979). Problems in the traditional view are a) there is a gradient from major to minor disturbance events (relative to the community), and b) some kinds of disturbance are initiated or promoted by the biotic component of the system.

Thus, a definition of disturbance must include environmental fluctuations as well as destructive events (Rykiel 1985, Neilson and Wullstein 1983), and allow for the fact that disturbance is relative to the spatial and temporal dimensions of the system under consideration. 'A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment' (White and Pickett 1985). This is a generalized definition where scale and process have to be specified for each site, and the occurrence of disturbance (cause) presupposes the existence of a detectable perturbation (effect) (Rykiel 1985). For example, disturbance to bryophyte communities on streamside boulders can occur on a spatial (10^{-4} m^2) and temporal scale (annual) that is irrelevant to the disturbance regime of the forest community growing on the same site (White and Pickett 1985, see also Sousa 1980). These authors suggest that a more meaningful working definition of disturbance would be to look at ratios of disturbance (e.g. patch size, return period) to organism (e.g. dominance of organism, life span of organism). This is

the first attempt to find a relativistic working definition of disturbance that changes with the frame of reference.

The importance of abiotic disturbance as part of the environmental context of lotic vegetation means that organismic (and hence allogenic and autogenic) models of vegetation are difficult to apply. Species composition is a function of the disturbance regime as well as other environmental variables, and competitive replacement in succession only occurs if disturbances cease to operate (White 1979). Conversely, Dawson (1978) has demonstrated how aquatic plants, themselves, alter the disturbance regime of a stream by increasing the hydraulic coefficient. Dawson and Robinson (1984) examined seasonal changes in biomass of submerged macrophytes in relation to hydraulic roughness and stream velocities. They concluded that the dominant plants have been forced to adapt, or selected for their ability, to maintain a low drag profile, and to maintain their presence, at least seasonally, in the high light conditions at the river surface in competition with other species.

Large-scale grazing (or biotic disturbance) by animals on aquatic vascular species is virtually non-existent (Gregory 1983, personal field observations), though the role of predation on aquatic plants in Australia is uncertain and Sainty and Jacobs (1981) report that Myriophyllum propinquum is grazed by the beetle Haltica ignea in summer. Ostrofsky and Zettler (1986) elegantly demonstrated the unpalatable nature of aquatic flowering plants to aquatic invertebrates and other herbivores. They analysed 15 species for the presence of alkaloids and found a total of 55, with between 2 and 9 alkaloids in each species. This variety reduces the chances of hungry herbivores developing a tolerance to the alkaloids and hence taking advantage of a new food supply. Insect predation appears to be an unimportant variable in the structure, composition and distribution of these vascular communities, unlike terrestrial plant communities (Springett 1978), benthic, filamentous and blue-green algae (Gregory 1983, Hynes 1970), and some aquatic bryophytes (Decamps and Lafont 1974).

The three primary strategies in plants defined by Grime (1977), represent a continuum between r- and K-selected species (see also Whittaker and Goodman 1979). In the most disturbed habitats, e.g. windswept krummholz or flood-battered riverbanks, the community is often depauperate in biomass and diversity. Here disturbance is so constant that it prevents high production, and plants must be structurally resistant to the disturbance (White and Pickett 1985). Grubb (1977) pointed out that coexistence through differential use of resources was unlikely to be important for plants because all have the same basic needs: light, carbon dioxide, water and nutrient elements. He also suggested that it is the ability of species to regenerate in gaps, where individuals have died, which ultimately determines species coexistence. Work by Werner (1979) also emphasizes the regeneration niche in plant communities, an emphasis which coincides with the increased awareness of the role of disturbance in determining the species composition of plant communities (Huston 1979).

This work has been complemented by that of Connell (1978), who examined diversity of trees in tropical rainforests, and corals on tropical reefs, as a function of storms. He delivered these ideas in the shape of the intermediate disturbance hypothesis. Connell deals more with levels of species richness and frequency of disturbance than previous work, and predicts that a greater biotic diversity will be maintained in communities subjected to intermediate levels of disturbance (whatever 'intermediate' might be), than in those undergoing either greater or lesser disturbance. Evidence of intermediate disturbances maintaining diversity levels (species richness) in streams is given by Ward and Stanford (1983), for benthic invertebrates by Statzner and Higler (1986), for stream insects by Stanford and Ward (1983), and for fish by Horwitz (1978).

Disturbance, as a means of continually forestalling competitive elimination of species (Fox 1977), is one aspect of the broader theoretical synthesis of spatial heterogeneity (Fox 1979), where temporally variable events that are partially independent in space (e.g. fires, treefalls, floods) can serve as a basis for niche diversification. Disturbance may result in a variable relationship between the realized and fundamental niches and therefore decreases the predictability of species composition from site attributes. This point has been reiterated by Harris (1980) who claims that the timing of a disturbance is the most crucial process for a community. The thesis therefore addresses the question:

* Is it more appropriate to consider a characteristic level of disturbance rather than 'homogenous' geographical subdivisions as a framework within which to examine lotic plant communities? (Chapter 2)

1.3.4 Physiographic plant geography

Physiographic plant geography is the study of plant distributions at the scale of landforms in relation to dynamic geomorphic processes which create various plant habitats (Zimmermann and Thom 1982). The physiographic approach therefore represents one point along a continuum of landforms (and hence vegetation) scales (Schumm and Lichty 1965). Such an individualistic approach is the result of geomorphic processes acting on materials with different properties, and assemblages of species which segregate on the different landforms with their different growth conditions. Within one geomorphic unit of the landscape, relative abundance of plants is controlled by biotic processes (e.g. interspecific competition) and abiotic disturbances. Presence or absence of species at the landform scale is determined ultimately by physical processes and is only secondarily modified by biotic factors.

This scenario echoes from the preceeding discussion, but synthesizes various ecological ideas which are pertinent to lotic plant communities:

a) The physiographic approach presupposes collaboration with hydrological and geomorphological processes. It lets these fields define units and processes of the physical landscape, independently of the vegetation.

b) The species is the basic unit of vegetation, because the species has specific physiologic-ecologic requirements. The species also has the advantage of being easily mapped.

c) The methodological core of physiographic plant geography is geographical, as it uses space and juxtaposition of spatial patterns to identify controlling factors. Plant-habitat correlations must be defined, tested and refined in as large an area as possible without crossing climatic and floristic boundaries.

d) The absence of a species from a particular habitat can be random, regardless of the suitability of the habitat for that plant's growth. Random absence can be due to, for example, the recurrent disturbance of floods, or natural cycles of mortality and regeneration. Distortions due to random absence are decreased as area increases.

e) The controls of plant populations are time dependent e.g. Zimmermann (1969) concluded that low frequency flood events (10 year recurrence interval) explained vegetation distributions in the mid-reaches of the San Pedro Valley.

f) Physiographic work assumes that vegetation always tends towards an equilibrium, even after a disturbance, and that a vegetation climax is probabilistic in an environment that is subject to disturbance. In areas that experience recurrent disturbance, the definition of random-time climax vegetation includes species that rely on disturbance for their regeneration.

A recent article by Salo et al. (1986) illustrates the physiographic approach. These authors suggest that large-scale forest disturbance and primary succession in Amazonian lowland rainforest are caused by erosion and channel changes of meandering rivers. In the upper Amazon, forest regeneration is mainly through primary succession on newly deposited river soils. This is contrary to the traditional view that rainforest regeneration is created by treefalls. Erosional disturbance is much more severe than disturbances caused by tree-falls, and regeneration on newly exposed fluvial deposits starts with the earliest phases of primary succession, rather than from established seedlings or well developed seed banks in tree-fall areas. Areas of riparian succession occur in long strips, along abandoned or recently-created river channels, and high levels of site disturbance lead to high between-habitat species diversity. Salo and his co-workers use these successional processes to classify the rainforests according to their geomorphological erosion-deposition pattern. This study aptly demonstrates how it is possible to elucidate mechanisms of plant distributions at a physiographic level. From this study, larger scale investigations could logically proceed in order to investigate, say, species distributions along a tributary, and larger scale regeneration patterns:

* Is the presence or absence of plant species between river catchments determined by dynamic physical processes which are only secondarily modified by biotic factors? (Chapter 5)

1.4 Predictability of lotic plant communities at different scales

Throughout this discussion it has been difficult to avoid the question of scale (both spatial and temporal). The problem of appropriate scales of investigation in plant ecological research is an age-old one (Kershaw 1973, Davis 1986), and is inextricably linked to concepts of predictability and stability of plant communities. It is not my intention to elaborate on this debate, but rather to comment on the predictability of lotic plant communities at different scales.

Connell and Sousa (1983) state that 'the spatial scale of a study will (also) affect judgements of the stability or persistence of a population or a community. If the population or community is defined for the purposes of the study as the assemblage on a small area, it is unlikely to be either stable or persistent, since even small perturbations could cause local extinction. In contrast, if the same assemblage is monitored over a very large area (which in effect averages out the variation in dynamics of subpopulations), it will be found to be persistent and possibly stable unless the species in question is (are) becoming extinct globally.' The time scale is also important as stability or persistence are responses to punctuated disturbances that do not cause long-term changes (i.e. longer than turnover time of the community) (Connell and Sousa 1983).

Several studies have been undertaken examining spatial patterns of aquatic macrophytes and riparian species at the regional scale (Goriup 1978, 1979, 1981, Haslam 1978, Wiegleb 1981a), at the catchment scale (Merry et al. 1981, Butcher 1933, Nilsson 1981, 1983, 1986), and for 50 metre sections of river (Wright et al. 1981). Predictability of plant vs. environment increases as the spatial scale decreases. Temporal studies at the catchment scale have been undertaken by Holmes and Whitton (1977a, 1977b), Wright et

al. (1981), and for a 50 metre stretch of river by Ham et al. (1981). Predictability of stream plant communities appears to increase as the time scale decreases. These studies have been undertaken in the northern hemisphere, along rivers which experience more predictable environmental variation than Australian ones.

This study therefore considers the following questions:

* does the variability of spatial and temporal scales of investigation affect the stability (and hence predictability) of riverine species and communities? (Chapter 6);

* if there are significant differences in stability of species and communities at varying scales, what implications do these variations have for the conservation and reservation status of riverine plants? (Chapter 6)

Chapter 2 Hydrology and chemistry of Tasmanian Rivers	
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	Can changes in species composition or cover (succession?) in lotic plant communities be predicted from life history characteristics of individual plant species?
Chapter 4 The vegetation of the Swan and Apsley Rivers	
	Is the diversity and richness of riverine plants highest in the mid reaches of streams where there is (possibly) maximization of environmental variability?
	Are plant species distributed in a continually varying fashion downstream in response to a 'continuous' or 'intergrading' longitudinal gradient of environments?
	Is the distribution and species composition of aquatic vascular plant communities influenced by the nature of the riparian communities and the terrestrial setting of the stream?
	Are deterministic physico-chemical processes a major influence on the distribution of plant communities along the length of a river?
Chapter 5 Distribution of plant communities along rivers in Tasmania	
	Is the presence or absence of plant species between river catchments determined by dynamic physico-chemical processes?
Chapter 6 Conclusion	
	Does the variability of spatial and temporal scales of investigation affect the stability (and hence predictability) of riverine species and communities?
	If there are significant differences in stability of species and communities at varying scales, what implications do these variations have for the conservation and reserve status of riverine plants?

Table 1. Summary of questions asked in chapter 1

Chapter 2

Hydrology and chemistry of Tasmanian rivers : spatial and temporal variability, and ecological implications.

2.1 Introduction

'A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability or the physical environment' (White and Pickett 1985). Hydrological variations (or disturbances) have been used as direct (Webster et al. 1983, Fisher et al. 1982, Bell and del Moral 1977, White 1979), and indirect (Yarbro 1983) explanations for the distributions of biota in and along streams. Other studies have indicated the effects of temperature disturbances (Taylor 1981, Vannote and Sweeney 1980), chemical disturbances (Norris et al. 1980, 1981, 1982) and 'experimental' disturbances (Reice 1984) for lotic environments.

Recent work (McMahon 1979a, 1982a) has demonstrated how Australian streams, as a whole, comprise a distinctive hydrological group that have more variable annual flows and more variable peak discharges than world streams. McMahon has also demonstrated that the mean peak annual floods of Australian streams are an order of magnitude larger than they are for world streams and exhibit larger skewness and kurtosis (McMahon 1982a). From this work one can deduce that levels of hydrological disturbance are potentially greater along Australian rivers than their northern hemisphere counterparts.

Temperatures in Australian perennial streams do not show the same degree of variability as discharge (Lake et al. 1985a), though the chemistry of lotic waters in Australia does appear to vary from other regions of the world. In addition

to the (apparent) dominance of sodium and chloride (Williams and Wan 1972), Hart and McKelvie (1986) and Buckney (1980) have demonstrated the importance of calcium, magnesium and bicarbonate in Australian lotic environments. Hart and McKelvie (1986) plotted the relationship between salinity and cationic composition for selected Australian rivers, compared the distribution with that of Gibbs' (1970) for rivers in North and South America, and so indicated the dominance of sodium in Australian lotic waters. Other studies have shown the dominance of waters like seawater in stoichiometry (Buckney 1976a, 1976b, Buckney and Tyler 1973, Williams and Buckney 1976, Bek and Bruton 1979).

This chapter a) regionalizes levels of hydrological and chemical variability, to use as a framework within which to examine lotic plant communities, and b) explores the hydrology and chemistry of lotic environments in Tasmania, to elucidate whether the hydrology and chemistry of Tasmanian rivers is spatially and temporally comparable to that of mainland Australian and world rivers.

2.2 Hydrological variability

2.2.1 Previous hydrological investigations of Tasmanian rivers

The few published studies that have been undertaken on the hydrology of Tasmanian rivers are very limited. They fall into three categories : specific investigations concentrating on flood magnitudes and peaks of particular catchments or regions (Watson 1975, 1983, Faircloth 1978, Fuller and Williams 1985, 1986, Roberts 1984, Knighton 1987a, 1987b); general hydrological descriptions of a region or river catchment (Guiler 1955, Watson 1978, Jordan 1975); indirect hydrological investigations associated with other river related studies (Bennison 1975, Norris et al. 1981, Olive 1973, Michaelis 1984, Thomson 1985). Low flow studies and investigations into the seasonality of hydrological

events along Tasmanian rivers are non-existent.

The island state of Tasmania is a distinctive hydrological region within the Australian continent (Bauer 1955, A.W.R.C. 1978). The west and south-west region of the island experiences one of the highest rainfalls for Australia (fig. 1), while the south-east and east coast have rainfall patterns akin to the drier mainland areas (Bureau of Meteorology 1975). A diverse rainfall regime can produce contrasting river hydrologies (Pattison 1977), but no regionalization or classification exists confirming or quantifying such hydrological diversity for Tasmania.

2.2.2 Hydrological classification of Tasmanian rivers

Objective regionalization or classification of river catchments has been a little discussed hydrological (Moseley 1981, Chapman 1975) and ecological tool, yet by defining regions within which rivers have similar hydrological regimes, it is possible to extrapolate data for catchments where no data are available. For stream ecologists, some idea of the hydrological environment in which stream organisms live is of crucial importance. It is therefore surprising that hydrological regionalization procedures have not been employed by stream ecologists for reconnaissance sampling, or as a framework within which to examine lotic communities. The present classification of Tasmanian river hydrologies provides some idea of seasonal and annual flow patterns as well as peak and low flow events.

Statistical methods have been used by hydrologists to test for homogeneity of hydrological response within subjective regional groupings (Pattison 1977, Linsley et al. 1975, Ward 1984), and many hydrologic regions have been based entirely on non-hydrologic, subjective criteria e.g. administrative boundaries in the U.K. Flood Studies Report (N.E.R.C. 1975). Beable and McKerchar (1981) used semi-quantitative approaches in identifying hydrologic regions in New Zealand, but these were not based entirely on hydrologic criteria and

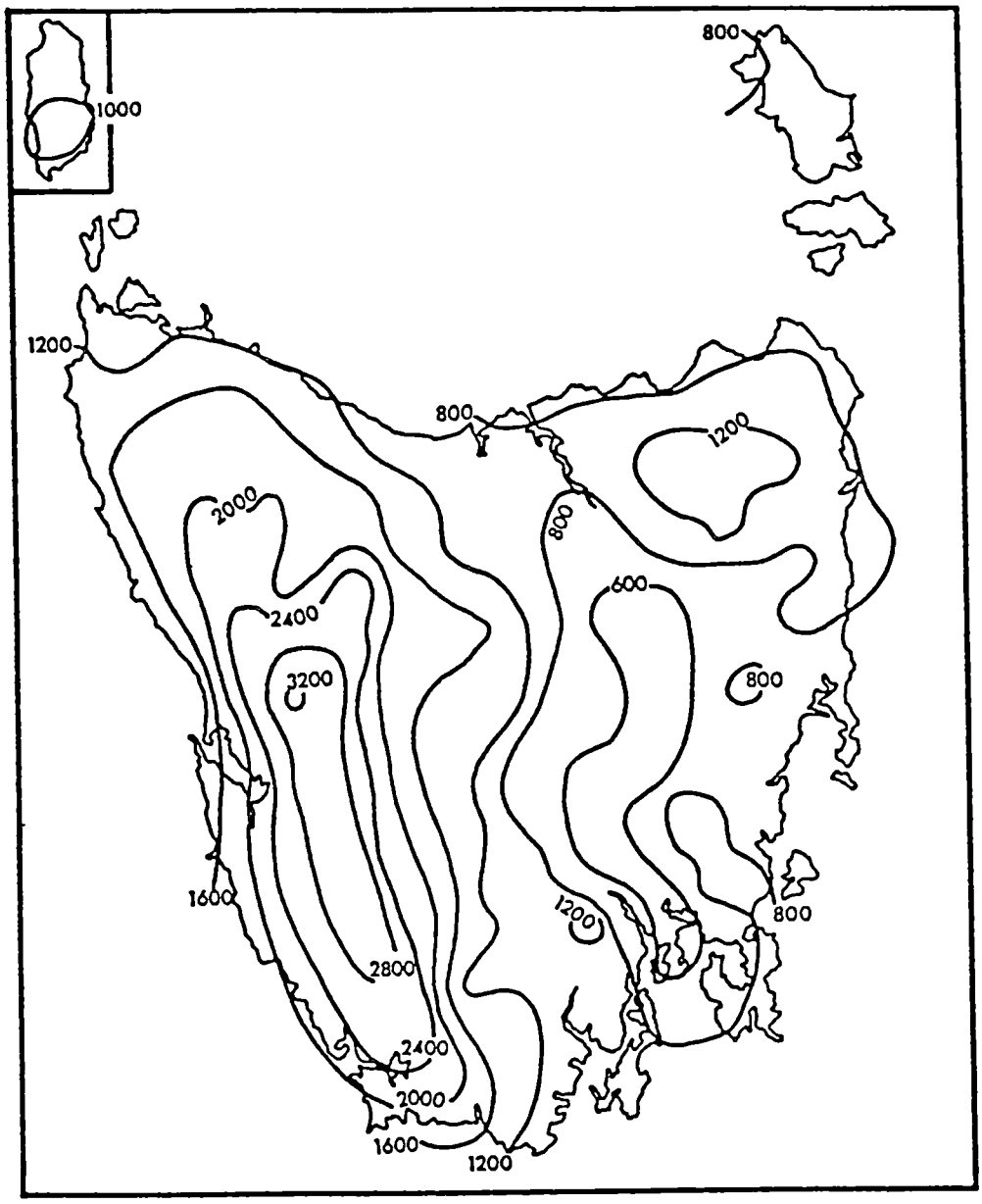


Fig. 1. Mean annual rainfall of Tasmania (mm). Reproduced from the Tasmanian Year Book (1985)

involved a substantial amount of subjectivity. Moseley (1981) attempted to improve their classification, but only used two hydrologic parameters, both based on mean annual flood data.

The Representative Basins Scheme (R.B.S.) in Australia and New Zealand has created a bulk of literature on regionalization of river catchments in these areas (Blake et al. 1970, Bell 1982, Fatchen and Lustig 1986). Representative basins are not created as hydrological benchmarks alone (Bell 1982), and thus regionalization for the R.B.S. has included other variables eg. geology, ecology, meteorology and management practices. Additionally, many catchments considered by the R.B.S. do not have adequate hydrologic data, thus excluding this variable from some catchment classification procedures.

Laut et al (1983a, 1983b, 1983c) classified sub-basins in the Macleay Valley, New South Wales, by identifying six groups of hydrologically significant landscape attributes. Principal coordinates analysis was used to determine the degree of similarity between catchments, and was also used to examine similarity of rainfall data for a set of test sub-catchments. Using a combination of rainfall and landscape measures, regression equations were used for predicting a range of hydrologic parameters. This procedure enabled observed hydrologic parameters in gauged catchments to be extrapolated to ungauged areas.

Low flow studies for Australian rivers are sparse (Ward 1984, McMahon 1976, McMahon 1973, McMahon and Dias Arenas 1982, Srikanthan and McMahon 1985), as are investigations into the seasonality of hydrological events along Australian rivers (McMahon 1979a, Ward 1984).

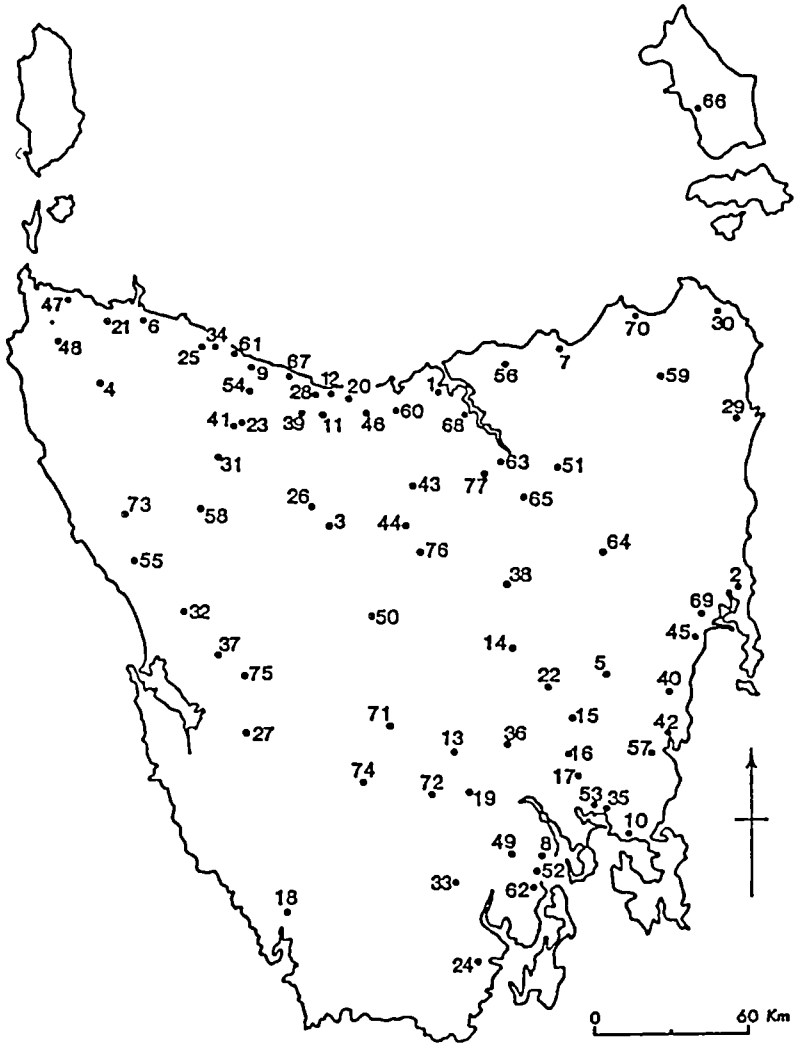
This section identifies a system of hydrologic regions in Tasmania, based entirely on objective hydrologic criteria. Data from 77 river gauges are used in the classification and each region is described in terms of the annual series, monthly series and low and peak flow series.

Data and Methods

Data from 77 gauging stations were analysed in this study. The gauging stations were located in 69 river catchments throughout Tasmania (fig. 2), with sizes ranging from 11 km^2 for the Pet River to 8997 km^2 for the South Esk River. A minimum of 15 years for each hydrological series was accepted, with the South Esk River having the longest record of 81 years. Pattison (1977) recommends a record of not less than 15 years because of the risk of unreliable estimates in discharge statistics. However, a 15 year hydrological series can be a problem in the annual summary statistics of mean and skewness, and this may be compounded for variable flow regimes where a 15 year record may be atypical. For peak and low flow series, a 15 year record can be influenced by extreme events.

Some of the rivers in the study have altered regimes due to the construction of impoundments or reservoirs along their course. In such situations only data collected prior to impoundment were used. The hydrological data for each of the gauging stations were obtained from the Rivers and Water Supply Commission of Tasmania and the Hydro-Electric Commission (see A.W.R.C. 1984, R.W.S.C. 1983).

It is inevitable that there is bias in any classification in terms of the variables chosen. However, annual flow series, monthly flow series, peak discharge series and low flow discharge series were obtained and twelve variables were calculated for each gauging station (Appendix 1). The monthly variables were considered to be an important measure of seasonality in the rivers' regime. The annual flow summaries do not give an idea of yearly extremes, thus peak and low flow records were also examined. Figures for mean annual runoff are necessary to establish the total water resources of a catchment, and coefficient of variation is a most useful measure of hydrological variability.



1. ANDERSON'S CREEK
2. APSLEY RIVER
3. ARM RIVER
4. ARTHUR RIVER
5. BIRRALEE CREEK
6. BLACK RIVER
7. BRID RIVER
8. BROWNS RIVER
9. CAM RIVER
10. CARLTON RIVER
11. CLAYTONS RIVULET
12. CLAYTONS RIVULET
13. CLYDE RIVER
14. CLYDE RIVER
15. COAL RIVER
16. COAL RIVER
17. COAL RIVER
18. DAVEY RIVER
19. DERWENT RIVER
20. DON RIVER
21. DUCK RIVER
22. DULVERTON RIVER
23. EMU RIVER
24. ESPERANCE RIVER
25. FLOWERDALE RIVER
26. FORTH RIVER
27. FRANKLIN RIVER
28. GAWLER RIVER
29. GEORGE RIVER
30. GREAT MUSSELROE RIVER
31. HELLYER RIVER
32. HENTY RIVER
33. HUON RIVER
34. INGLIS RIVER
35. IRON CREEK
36. JORDAN RIVER
37. KING RIVER
38. LAKE RIVER
39. LEVEN RIVER
40. LITTLE SWANPORT RIVER
41. LOUDWATER RIVER
42. MACLAINES CREEK
43. MEANDER RIVER
44. MEANDER RIVER
45. MEREDITH RIVER
46. MERSEY RIVER
47. MONTAGU RIVER
48. MONTAGU RIVER
49. MOUNTAIN RIVER
50. NIVE RIVER
51. NORTH ESK RIVER
52. NORTH WEST BAY RIVER
53. ORIELTON RIVULET
54. PET RIVER
55. PIEMAN RIVER
56. PIPERS RIVER
57. PROSSER RIVER
58. QUE RIVER
59. RINGAROOMA RIVER
60. RUBICON RIVER
61. SEABROOK CREEK
62. SNUG RIVER
63. SOUTH ESK RIVER
64. SOUTH ESK RIVER
65. SOUTH ESK RIVER
66. SOUTH PATS RIVER
67. SULPHUR CREEK
68. SUPPLY RIVER
69. SWAN RIVER
70. TOMAHAWK RIVER
71. FLORENTINE RIVER
72. TYENNA RIVER
73. WHYTE RIVER
74. GORDON RIVER
75. FRANKLIN RIVER
76. PINE TREE RIVULET
77. MEANDER RIVER

Fig. 2. Location of the 77 gauging stations

The variables used in the analysis were:

Coefficient of variation (annual flows)	Cv
Mean annual runoff	M.A.R. (mm)
Coefficient of skewness (annual flows)	Cs
Serial correlation coefficient (annual flows)	r_1
Coefficient of variation (monthly flows)	Cv monthly
Coefficient of variation (monthly peaks)	Cv monthly $\overline{Q}$ max
Coefficient of variation (monthly lows)	Cv monthly $\overline{Q}$ low
Specific mean peak annual discharge	$\overline{Q}$ max (m^3/s /km^2)
Index of variability (log peak flows)	Iv
Coefficient of skewness (log peak flows)	g
Specific mean low annual discharge	$\overline{Q}$ low (m^2/s /km^2)
Index of variability (low flows)	Iv low

The 12 x 77 matrix was analysed using principal coordinates analysis and complete linkage cluster analysis. The computer program Genstat (1977) was employed for both procedures. Additionally, a stopping rule criterion (Ratkowsky 1984) was applied to the complete linkage analysis to determine the optimum number of groups in the classification.

Principal coordinates analysis is a generalization of principal components analysis, but unlike the latter allows the use of distance or similarity measures and is not restricted to Euclidean distance. Consequently principal coordinates analysis is a suitable ordination technique for the analysis of the 12 x 77 hydrological matrix (unlike principal components analysis), and has an advantage over principal components analysis when a visual representation of the data is sought. The closer the catchments are to each other in the space defined by the axes, the more similar they are (Everitt 1978, Chatfield and Collins 1980).

Several clustering strategies were employed experimentally (single linkage cluster analysis, complete linkage cluster analysis and centroid cluster analysis), and the results of the complete linkage cluster analysis were used. Although complete linkage cluster analysis produced the tightest

clusters of similar samples, the technique tends to artificially sharpen the cluster boundaries. Thus a stopping rule was employed in order to find the partition that maximized the overall average similarity of the groups produced by the classification (Ratkowsky 1984). Both ordination and classification are used to objectively regionalize the river hydrology of Tasmania, however, it is acknowledged that these methods cannot give a unique or perfect answer.

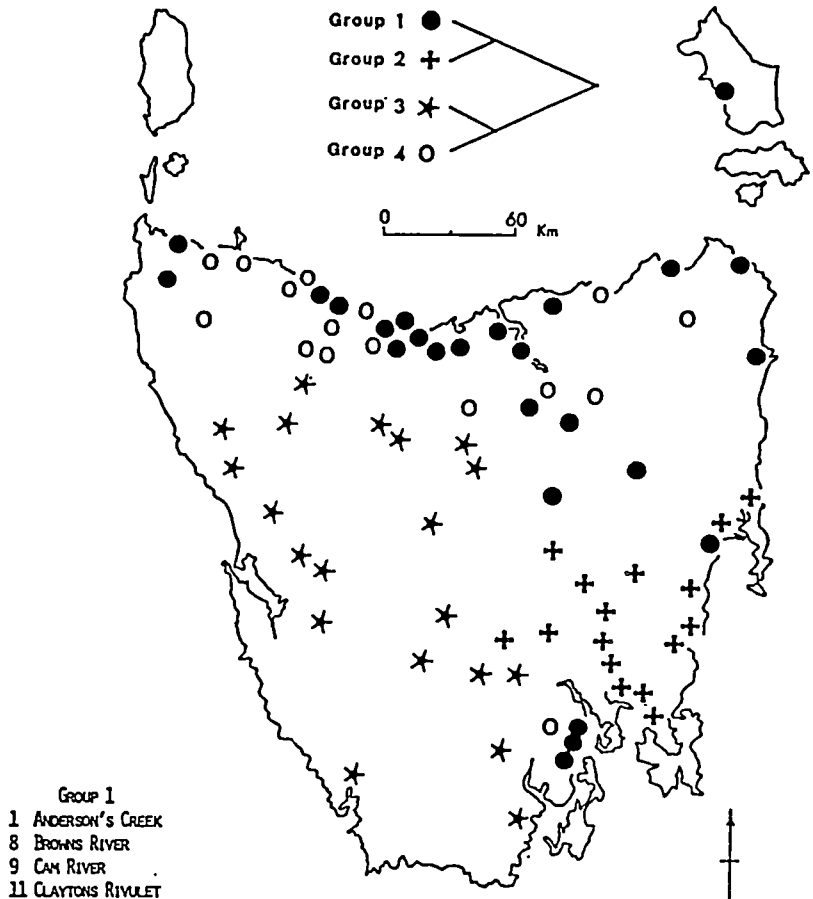
Classification

The classification of the 77 stations differentiates four distinctive and spatially significant categories (fig. 3). Group 2 consists of the south-eastern stations and is placed closest to group 1 in the dendrogram. This latter group includes stations on the north-central coast, the Midlands, the north-east and three stations south of Hobart. Group 3 includes all rivers in the south and west, while group 4 stations form an arc from the north-west stations to the north-east. The results of the principal coordinates analysis are graphically represented in figure 4, which highlights the relationships between the rivers in the survey. One axis corresponds to a continuum of variability of annual hydrological events, and a second axis is closely related to the change from high to low seasonality. Both the classification and ordination demonstrate that it is possible to build an objective regionalization model by using variables from a variety of hydrological data.

2.2.3 Comparisons with other regions in Australia and the world

Annual Flows

Group 3 has the highest mean annual runoff (MAR) of 1347 mm (table 2). Group 2 has the lowest MAR of 142 mm, and is also the region which experiences the lowest annual rainfall (fig



Group 1
1 Anderson's Creek
8 Browns River
9 Cam River
11 Claytons Rivulet
12 Claytons Rivulet
20 Don River
28 Gahler River
29 George River
30 Great Musselroe River
38 Lake River
45 Meredith River
46 Mersey River
47 Montague River
48 Montague River
52 North West Bay River
56 Pipers River
60 Rubicon River
61 Seabrook Creek
62 Snug River
64 South Esk River
65 South esk River
66 South Pats River
68 Supply River
70 Tomahawk River
77 Meander River

Group 2
2 Apsley River
5 Birralee Creek
10 Carlton River
13 Clyde River
14 Clyde River
15 Coal River
16 Coal River
17 Coal River
22 Dulverton Creek
35 Iron Creek
36 Jordan River
40 Little Swanport River
42 Maclaines Creek
53 Orielton Rivulet
57 Prosser River
69 Swan River

Group 3
3 Arm River
18 Davey River
19 Derwent River
24 Esperance River
26 Forth River
27 Franklin River
31 Hellyer River
32 Henty River
33 Huon River
37 King River
44 Meander River
50 Nive River
55 Pieman River
58 Que River
71 Florentine River
72 Tyenna River
73 Wyte River
74 Gordon River
75 Franklin River
76 Pine Tree Rivulet

Group 4
4 Arthur River
6 Black River
7 Brid River
21 Duck River
23 Emu River
25 Flowerdale River
34 Inglis River
39 Leven River
41 Loudwater River
43 Meander River
49 Mountain River
51 North Esk River
54 Pet River
59 Ringarooma River
63 South Esk River
67 Sulphur Creek

Fig. 3. Classification of the stations using complete linkage analysis and the stopping rule criterion

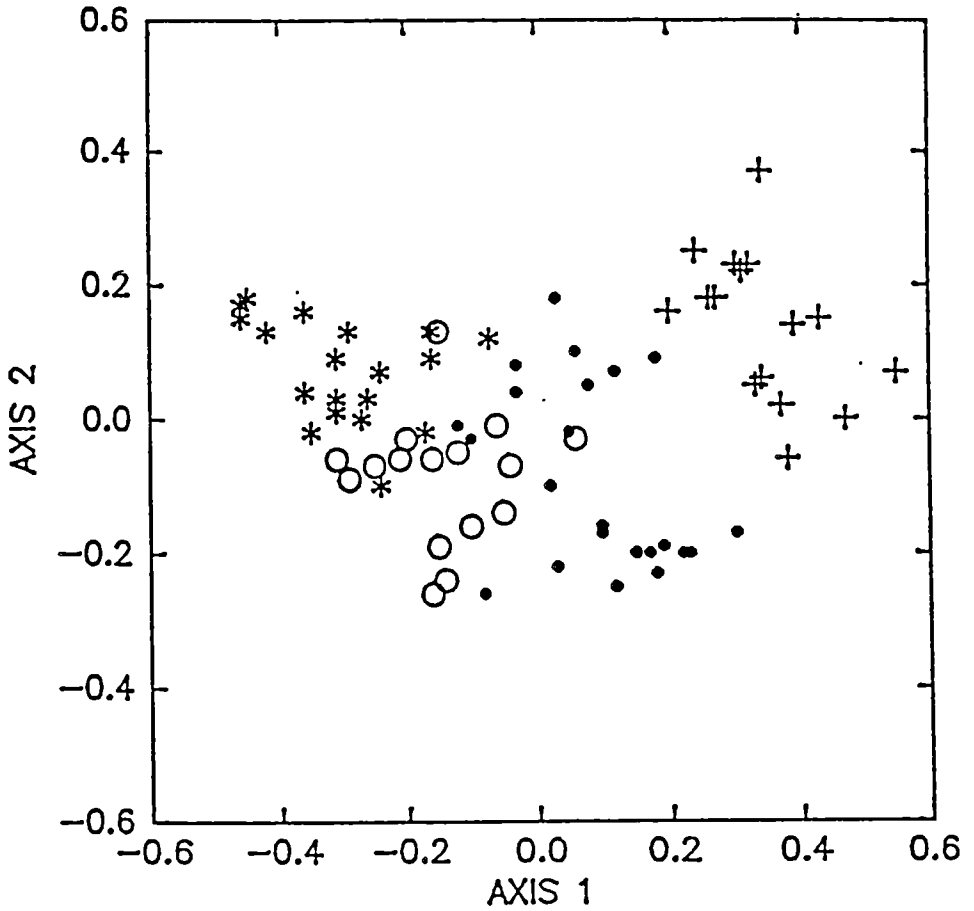


Fig. 4. Principle coordinates analysis scores on axes 1 and 2 with classification superimposed: Group 1 = • ; Group 2 = + ; Group 3 = * ; Group 4 = O

		ANNUAL FLOWS				MONTHLY FLOWS		
		M.A.R. (mm)	Cv	Cs	r_1	Cv monthly	Cv monthly $\bar{Q}$ max	Cv monthly $\bar{Q}$ low
Group 1 n = 25	$\bar{x}$	410	0.52	0.75	0.11	0.73	0.66	1.19
	σ_n	133	0.09	0.57	0.19	0.17	0.14	0.35
	Range	225 - 684	0.43 - 0.78	-0.12 - 2.3	-0.34 - 0.37	0.39 - 1.02	0.34 - 0.87	0.44 - 2.25
Group 2 n = 16	$\bar{x}$	142	0.87	1.04	0.18	0.70	0.67	1.44
	σ_n	104	0.08	0.36	0.18	0.19	0.21	0.48
	Range	29 - 402	0.76 - 1.08	0.55 - 1.8	-0.24 - 0.51	0.39 - 1.01	0.39 - 1.1	0.46 - 2.36
Group 3 n = 20	$\bar{x}$	1347	0.23	0.46	-0.19	0.49	0.44	0.67
	σ_n	511	0.04	0.49	0.19	0.09	0.08	0.24
	Range	271 - 2339	0.14 - 0.33	-0.19 - 1.18	-0.64 - 0.26	0.35 - 0.65	0.27 - 0.62	0.32 - 1.45
Group 4 n = 16	$\bar{x}$	762	0.36	0.15	0.12	0.65	0.54	0.91
	σ_n	285	0.07	0.50	0.27	0.09	0.09	0.27
	Range	200 - 1203	0.27 - 0.51	-0.97 - 0.48	-0.42 - 0.61	0.30 - 0.76	0.37 - 0.80	0.58 - 1.63

		PEAK FLOWS			LOW FLOWS	
		$\bar{Q}$ max ($m^3/s/km^2$)	Iv	g	$\bar{Q}$ low ($m^3/s/km^2$) x 10^{-4}	Iv low
Group 1 n = 25	$\bar{x}$	0.39	0.29	-0.43	6.6	0.94
	σ_n	0.25	0.10	0.62	5.5	0.50
	Range	0.10 - 1.01	0.14 - 0.56	-1.77 - 0.66	0 - 24.6	0.34 - 2.28
Group 2 n = 16	$\bar{x}$	0.46	0.69	-1.08	0.36	1.87
	σ_n	0.41	0.19	0.75	0.6	1.26
	Range	0.01 - 1.5	0.59 - 1.12	-2.46 - 0.32	0 - 2.31	0 - 5.0
Group 3 n = 20	$\bar{x}$	0.74	0.16	0.13	29.06	0.48
	σ_n	0.64	0.05	0.97	15.2	0.56
	Range	0.10 - 2.83	0.09 - 0.28	-3.23 - 1.58	0.46 - 53.3	0.15 - 2.78
Group 4 n = 16	$\bar{x}$	0.36	0.19	-0.17	24.28	0.46
	σ_n	0.21	0.07	0.73	10.2	0.16
	Range	0.08 - 1.01	0.11 - 0.33	-1.39 - 1.72	4.01 - 38.5	0.22 - 0.79

Table 2. Summary statistics for each of the 12 hydrological variables in the 4 groups

1). McMahon (1982a, 1982b) calculated average MAR for various regions of the world, with an average for Australia of 404 mm. The arid Australian zone has an average of 21 mm and the world average is 360 mm. In the UNESCO (McMahon 1982b) study very few of the rivers have runoffs exceeding 1000 mm (Amazon River has MAR of 1010 mm). Most temperate rivers have MAR of 250 - 499 mm, and the majority of the semi arid regions have runoffs of 50 -250 mm.

Thus MARs in groups 1 and 4 can be compared with those in temperate regions. Group 3 appears to have no recorded counterpart, as MAR for 15 out of 20 river catchments exceeds 1000 mm. At the other extreme, group 2 contains 7 out of 16 catchments with runoffs comparable with those of semi-arid regions.

The coefficient of variation (Cv) of annual flows is defined as the standard deviation divided by the mean of the annual flows. Groups 2 and 3 have the highest and lowest Cv of annual flows respectively (table 2). McMahon (1982b) demonstrated that tropical and cold region rivers are 25% less variable than those in semi-arid and temperate regions. This is due to the greater reliability and consistency of rainfall in regions with lower coefficients of variation of annual flows. The average world Cv is 0.27, and the average for Australian rivers is 0.75. Ward (1984) calculated an average of 0.72 for rivers in northern New South Wales. For world arid zones the average Cv is 0.91, while Australian arid zones average 1.27 (see McMahon 1979b, 1982a, 1982b). Group 2 coefficients of variation are compatible with drier regions in the world, whilst group 3 results are characteristic of regions with heavy, reliable rainfalls.

It has been found that regions with low MAR have high variability (A.W.R.C. 1978, Linsley et al 1975, McMahon 1982b). This relationship is displayed in fig. 5, where Cv is plotted against MAR. A least squares fit of the data yields a significant relationship ($r = 0.85$, $p < 0.001$). The graph demonstrates that stream variability is exponentially

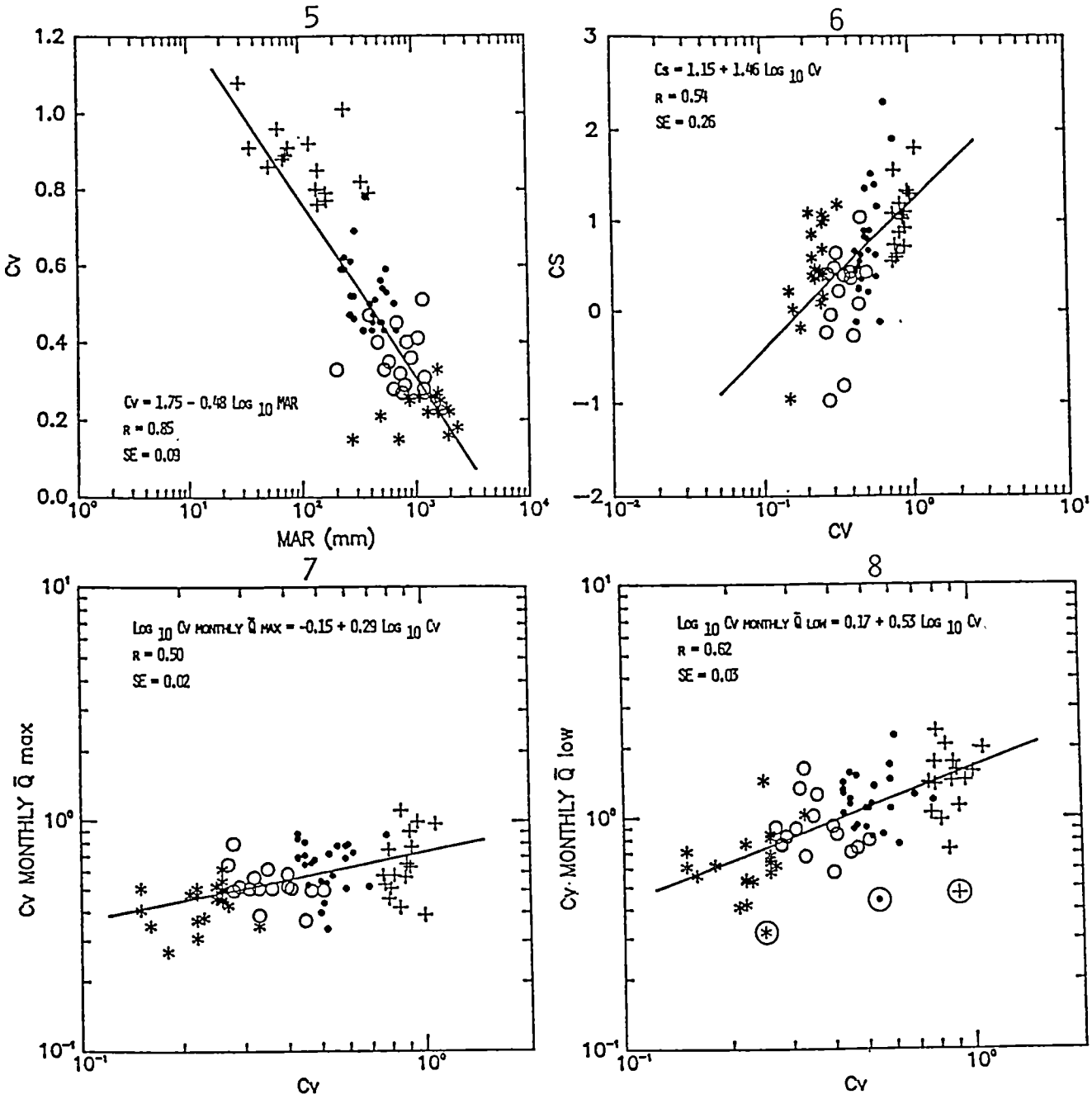


Fig. 5. Least squares relationship between the coefficient of variation of annual flows and mean annual runoff

Fig. 6. Least squares relationship between the coefficient of variation and skewness of annual flows

Fig. 7. Least squares relationship between the coefficient of variation of annual flows and the coefficient of variation of peak monthly flows

Fig. 8. Least squares relationship between the coefficient of variation of annual flows and the coefficient of variation of low monthly flows

related to mean annual runoff. Kalinin (1971) concluded that stream variability was affected by drainage area, but no significant relationship was found between drainage area and Cv for the rivers in the study area ($r = 0.15$, $p > 0.05$).

Table 2 demonstrates that group 2 has the highest positive skewness. Interestingly, it is group 4 that has the most normally distributed rivers with an average of 0.15. This is possibly due to the rivers' proximity to the constancy of low pressure weather systems in Bass Strait, and also due to Cs not standing out as a regionally distinct variate in the classification (note the high standard deviation). Statistically, regions with greater MAR are likely to have less skewed distributions. A least squares fit of Cv plotted against Cs (fig. 6) shows a general relationship of Cs increasing with Cv ($r = 0.54$, $p < 0.001$). This supports the findings of McMahon (1979b) who demonstrated that the average value of Cs for world arid zones is 1.8, which is several times larger than the average skewness for humid regions.

The effect of one event on a following event in a time series is defined as persistence, and can be measured using the lag one serial correlation coefficient (r_1). Values of r_1 for the four groups are shown in table 2, but the groups also display wide ranges and high standard deviations. All r_1 values are predominantly low, and Anderson (1962) demonstrates how short records, with values of $r < 0.3$, are not statistically different from zero. However, even a small correlation will reduce the effect of the random term and increase the persistence term of the generating function. It has been suggested that water carryover is greater in humid regions (Yevdjevich 1964), and McMahon (1982a) has shown that the mean r_1 for Australia is 0.13, and for Australian arid zones is 0.04. Yevdjevich (1963), Kalinin (1971) and McMahon (1982b) calculated world averages of 0.15, 0.15 and 0.23 respectively. McMahon's world figure has a range of -0.14 to 0.77. Only 6 of the 77 values in this study are different from zero at the 5% level of significance,

suggesting that carryover storage is not significant in Tasmanian catchments. The lack of serial correlation in the humid south-west (group 3) is possibly due to the steep, rocky nature of the basins, discouraging storage effects. Klemes (1970) suggested that low coefficient of skewness values could be associated with large values of persistence. This postulated relationship is (relatively) not a strong one for the Tasmanian data set when r_1 is plotted against Cs for the 77 stations ($r = 0.30$, $p < 0.01$).

Monthly Flows

To examine the pattern of seasonal flows in Tasmania, the coefficient of variation of average monthly flows (Cv monthly) is considered (table 2). The data reveal that the most consistent Cv monthly (0.49) occurs for group 3. Groups 2 and 1 have the highest average Cv monthly, indicating the greatest variability for monthly flows. There are no published data with which to compare these results. It is possible that regions with variable annual flows and low mean annual runoff have variable monthly flows. Plotting Cv annual flows with Cv monthly flows does not reveal a very strong correlation ($r = 0.40$, $p < 0.001$).

The Cv of mean peak monthly flows (Cv monthly $\bar{Q}$ max) is plotted against Cv of annual flows (fig 7). A more significant correlation is revealed, indicating that regions with higher variability of annual flows tend to have more variable peak events. Again, group 3 (table 2) has the lowest variability of monthly peaks (0.44), and groups 1 and 2 have similar Cv monthly $\bar{Q}$ max with 0.66 and 0.67 respectively.

The most significant results are for the coefficient of variation of mean monthly low flows (Cv monthly $\bar{Q}$ low). Group 2 has the highest average of 1.44, followed by group 1, group 4 and group 3 with 1.19, 0.91 and 0.67 respectively. When Cv monthly Q low is plotted against Cv annual flows (fig 8), there is a significant correlation (r

= 0.62, $p < 0.001$). The Clyde, George and Florentine Rivers have particularly low Cv monthly $\bar{Q}$ lows for their groups. If these three outlying points are removed (circled on the graph), the correlation is improved ($r = 0.70$, $p < 0.001$). This implies that the drier eastern areas of Tasmania, with higher coefficients of variation of annual flow, have higher variability of monthly lows.

Peak Flows

Specific mean peak discharge ($\bar{Q}$ max $m^3/s/km^2$) is the mean peak annual discharge divided by the catchment area. This is an index of catchment flood response. The rivers in the south and west of Tasmania (group 3) experience the highest average specific mean peak discharges (0.74 $m^3/s/km^2$), and the highest standard deviations. This is surprising, as the results in the UNESCO report (McMahon 1982b) demonstrate that Australian and arid zone streams have higher specific peak discharges than world rivers. In order to investigate this unusual pattern, specific mean floods are plotted against mean annual runoff. When plotted as individual groups, it is seen that there is some relationship between specific peak discharge and M.A.R. (fig 9). Group 2 rivers emerge distinctively from combined group 3 and 4 rivers, and group 1 has a negative and weak correlation ($r = -0.25$, $p > 0.05$). This demonstrates that MAR and specific peak flows are quite independent for group 1. From the graph it is possible to see that the drier south-eastern rivers do have higher specific floods than the wetter catchments, which demonstrates how the wide range of values for each group distorts the mean.

Mean peak annual flows ($\bar{Q}$ max m^3/s) are plotted against catchment area (fig 10).The correlation ($r = 0.84$, $p < 0.001$) indicates a marked relationship between catchment area and mean peak flows for Tasmanian rivers, and a complete lack of group specificity. This demonstrates that catchment area is a reliable surrogate for mean peak discharge. However, the Clyde River (+ outlier) experiences

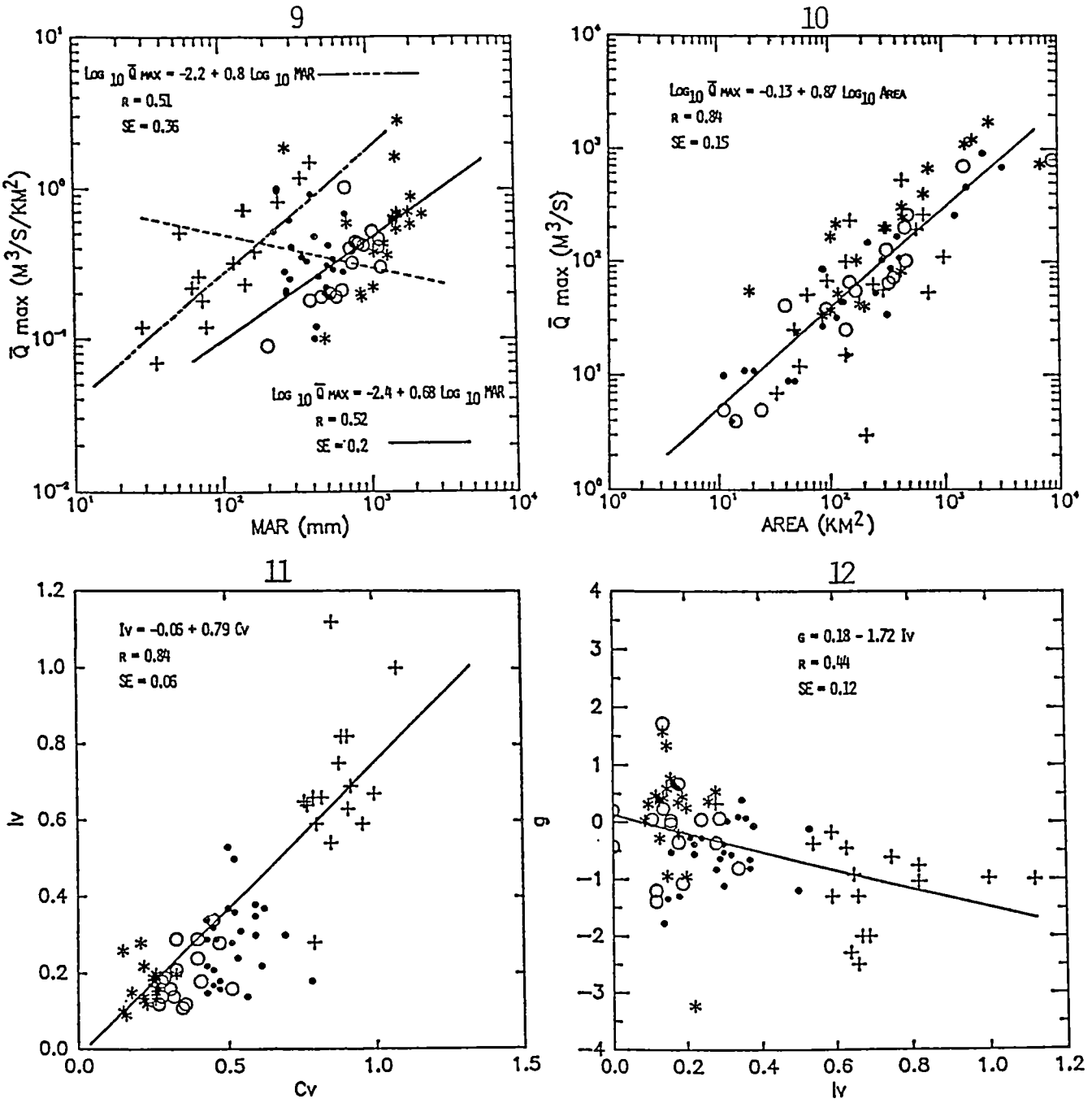


Fig. 9. Least squares relationships between specific mean peak annual discharge and mean annual runoff for group 2 (_ ... _), group 1 (------), and groups 3 and 4 (_____)

Fig. 10. Least squares relationship between mean peak annual flows and catchment area

Fig. 11. Least squares relationship between the index of variability of peak flows and the coefficient of variation of annual flows

Fig. 12. Least squares relationship between the coefficient of skewness of $\log_{10}$ peak flows and the index of variability of $\log_{10}$ peak flows

the least efficient floods per catchment area, probably because it flows out of a lake.

The standard deviation of the logarithms of peak annual flows is called the index of variability (Iv). As expected group 2 has the highest group mean of 0.69, followed by groups 1,4 and 3 with 0.29, 0.19 and 0.16 respectively. The mean value (and range) for Australia is 0.35 (0.12 to 1.3) and for Australian arid zones 0.65 (0.35 to 0.90) (McMahon 1982a). Iv of group 2 emerges distinctively, whereas groups 3, 4 and 1 have results more characteristic of humid environments. Pattison (1977) quotes average values of 0.3 to 0.6 for dry areas, and 0.1 to 0.4 for wet regions. In figure 11 the index of variability of annual floods is plotted against the Cv of annual flows. There is a significant relationship between the two variables ($r = 0.84$, $p < 0.001$).

The shape of the distribution of the logarithms of peak annual flows is the coefficient of skewness (g). Again, group 2 has the highest value of -1.08, and group 3 has the most normal distribution (0.13). McMahon (1979b) shows that Australian arid zones have a mean (and range) of -0.89 (-2.3 to 1.2) and the world average is -0.17 (-4.4 to 6.0). Boyd (1978) calculated an average g of -0.5 for New South Wales, and Victoria has an average of -0.3 (Kneen 1979 in McMahon 1982a). Figure 12 shows g plotted against the index of variability of log peak flows, and demonstrates a trend towards decreased skew with greater Iv. This is consistent with the pattern that rivers with smaller MAR have greater variability and greater positive skewness than wetter catchments.

Low Flows

The mean low annual discharge divided by catchment area is the specific mean low annual discharge ($\overline{Q}$ low $m^3/s/km^2$). Analyses of the 77 gauging stations for Tasmania, showed that lowest specific lows were for group 2, and the highest for group 3 (29.06 $m^3/s/km^2$). As expected, the lowest lows

occur in the dry south-east of Tasmania, followed by the north-central and Midlands rivers (group 1).

Specific mean low annual flows were plotted against MAR, and showed a significant relationship (fig 13), indicating that basins with low MAR tended to have low $\overline{Q}$ low $m^3/s/km^2$). Conversely, when mean low annual flows ($\overline{Q}$ low m^3/s) were plotted against area (fig 14), the correlation fell into two distinct groups: group 2 rivers and the rest. Both groups showed a significant trend, indicating that an increase in catchment area produced a higher mean low annual flow.

An investigation into the geographical distributions of the index of variability of low flows (Iv low) revealed that the south-east rivers had the most variable low flows, followed by the north-central and Midlands rivers. The north-western rivers had the lowest variability, which is possibly due to the deep volcanic soils in this region creating high water storage and persistent baseflow. Figure 15 shows the index of variablity of low flows plotted against specific mean low annual discharge. There is a significant correlation ($r = -0.8$, $p < 0.001$), which demonstrates that rivers with low specific mean annual lows have high variability of low flows.

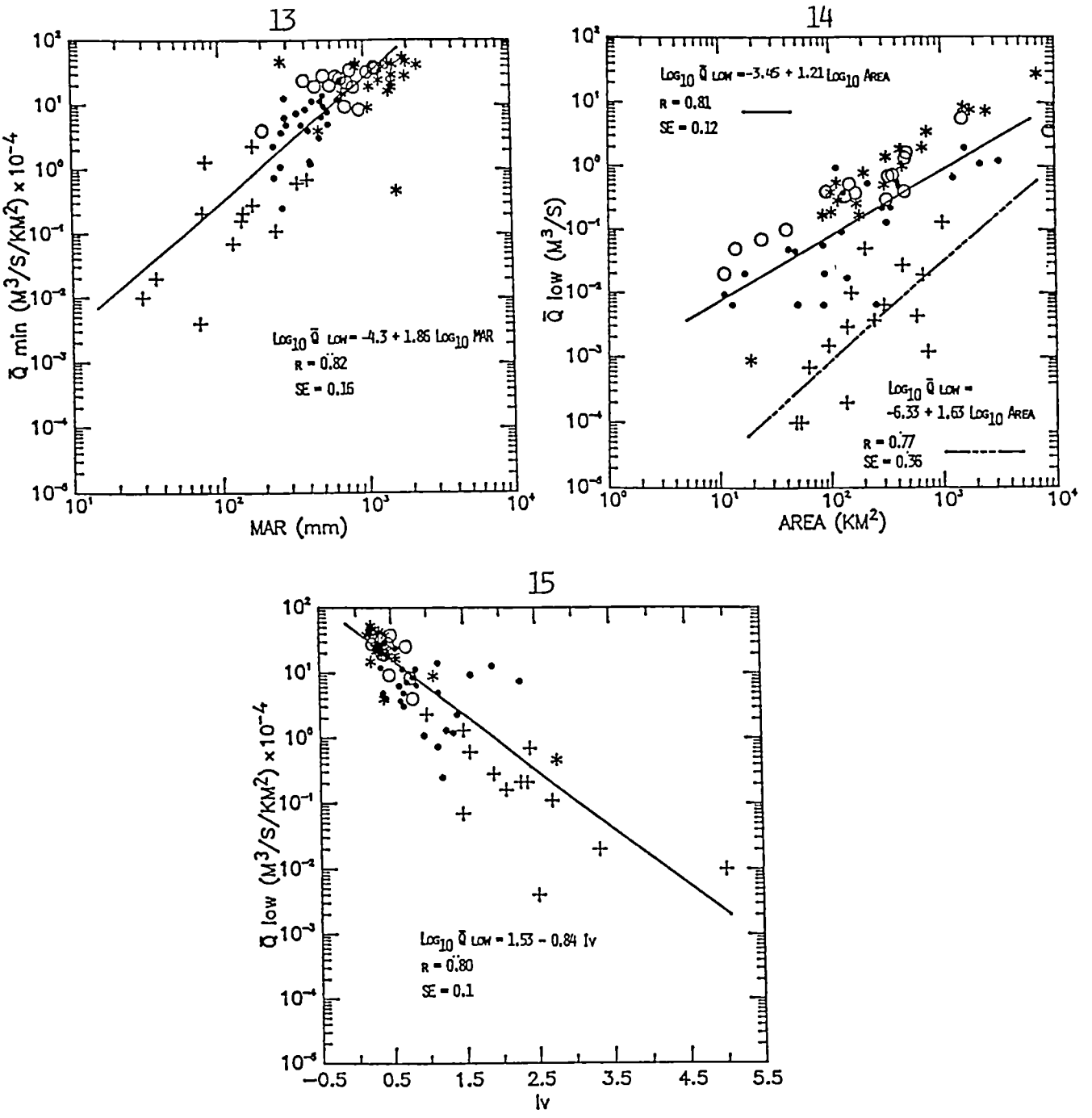


Fig. 13. Least squares relationship between specific mean low flows and mean annual runoff

Fig. 14. Least squares relationships between mean low annual flows and catchment area for group 2 (— ... —) and groups 1, 3 and 4 (———)

Fig. 15. Least squares relationship between the index of variability of low flows plotted against specific mean low annual flows

2.3 Chemical variability

2.3.1 Previous chemical investigations of Tasmanian rivers

The Midlands, north-east and south-east of Tasmania experience a sub-humid climate, where annual precipitation is less than annual evaporation (Gentilli 1972, Nunez 1978), and Buckney and Tyler (1976) have shown how lagoons in these areas are more saline than the majority of Tasmania's lakes and rivers (TDS > 300 $mg\ L^{-1}$). Metamorphosed pre-Permian rocks in the western regions of Tasmania contrast with the Central Plateau and drier eastern areas which are dominated by Jurassic dolerite (Davies 1965). This geological discontinuity can be reflected in the stoichiometry (sensu Buckney 1976b) of river waters in Tasmania.

The chemistry of Tasmanian lotic waters has been more widely studied than the hydrology. Buckney and Tyler (1973) undertook the first spatial investigation of the chemistry of Tasmanian waters, sampling lentic as well as lotic environments. The survey covered 170 sample sites, 66 of which were sampled in running waters. They concluded that most of the waters in Tasmania are dilute (TDS < 50 $mg\ L^{-1}$),and have sea water ionic composition. Geochemical and evaporation-crystallization processes modify this general pattern, where there are easily weathered rocks or high evaporation precipitation ratios respectively. The survey concluded that rivers have higher silica concentrations than lakes (as high as 20 $mg\ L^{-1}$), and tend to be enriched in bicarbonate and anions. In other words, proportions of calcium, magnesium and bicarbonate are higher compared with seawater.

Temporal investigations of the chemistry of Tasmanian lotic waters have been undertaken for the Derwent River by Buckney (1977), for the South Esk River by Norris *et al.* (1980), Tyler and Buckney (1973), and for the Gordon River by King and Tyler (1982). Under high flow conditions, the Derwent

River changed in stoichiometry from HCO_3^- > Cl^- > SO_4^{2-} : Na^+ > Ca^{2+} > Mg^{2+} > K^+ to Cl^- > HCO_3^- > SO_4^{2-}: Ca^{2+} > Mg^{2+} > Na^+ > K^+ (Buckney 1977), which represented a change to sodium chloride dominance from alkaline earth bicarbonates. Colour, turbidity and silica were high during high flows, while pH dropped during higher winter flows as a response to photosynthetic activity. King and Tyler (1982) demonstrated a similar ionic fluctuation with varying river discharge for the Franklin and Collingwood Rivers, and for the Gordon River before it was regulated by the dam. Post impoundment and regulation of the Gordon River reduced chemical variability, both in terms of concentration (salinity) and ionic composition, and reduced temperature variability of the water. Changes in sodium, calcium, magnesium and alkalinity were measured in the South Esk River after increased precipitation and river discharges (Norris et al. 1980). The above studies showed a general down-stream increase in total dissolved solids.

Sections 2.3.2 and 2.3.3 present the results of a survey to investigate the spatial and temporal variability of lotic water chemistry in Tasmania. Data on the temporal and spatial variation of lotic chemistry will indicate potential "disturbance" environments in Tasmanian rivers. A discussion and comparison of these results is produced in section 2.3.4.

2.3.2 Temporal variability of lotic water chemistry

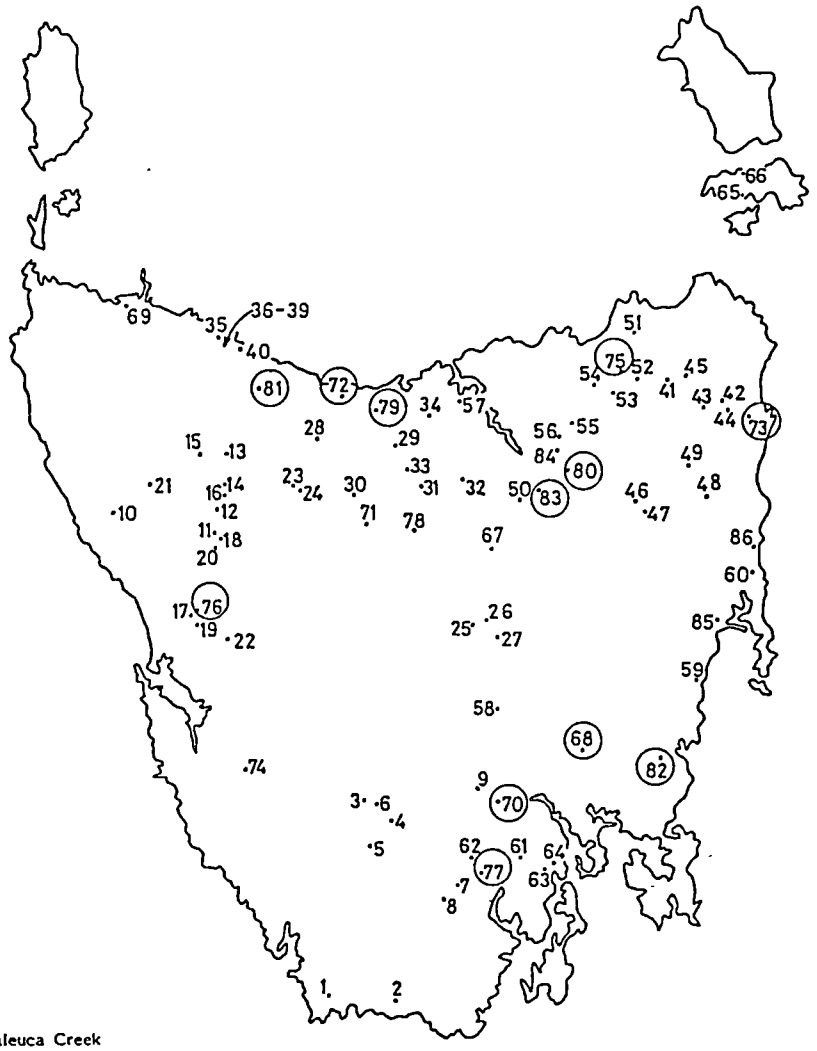
The above evidence indicates that there is temporal variability of ionic composition of lotic waters in Tasmania, as well as variability of other attributes such as pH, conductivity and turbidity. It was thus deemed necessary to analyse the chemistry of selected rivers in Tasmania over time and in relation to discharge fluctuations, in order to meaningfully interpret the results of a spatial water chemistry survey.

Data and methods

Temporal data from 12 rivers in Tasmania were analysed in this survey (* on fig. 16), and are representative of the four hydrological regions described in the previous section. The data were obtained from the Rivers and Water Supply Commission of Tasmania (see R.W.S.C. 1983), and for each river, samples were collected during rising, falling and steady hydrological events. The frequency and length of sampling is summarized in table 3.

The variables considered were chosen in the light of work by Haslam (1978) and Sculthorpe (1967) who have documented the chemical environment of aquatic plants. These were: temperature (^{o}C); pH; non filterable residue (glass fibre filter and drying at 105^{o}C, in $mg\ L^{-1}$); filterable residue (filtrate dried at 105^{o}C, in $mg\ L^{-1}$); colour (hazen units); dissolved oxygen (Winkler method, $mg\ L^{-1}$); sodium, magnesium, calcium, potassium (atomic absorption spectrophotometry, in p.p.m.); bicarbonate (titrimetrically with standard acid); chloride (argentometric method); sulphate (gravimetric method with barium chloride). All methods are outlined in the American Health Association Handbook (1971). Non filterable residue is analogous with suspended sediment, and filterable residue with total dissolved solids (A.H.A.H. 1971). The inaccuracies involved with measuring non filterable residue have been debated (Burkham 1985), and it is acknowledged that there may be underestimation in the data presented for this paramenter.

Ternary (or trilinear) diagrams are used to display the water chemistry data for each of the 12 rivers, and are a useful tool in water-analysis interpretation (see Hem 1985). Points plotted on the triangular graphs are projected onto the quadrilateral, thus enabling trends in ionic composition with changing streamflow to be observed. Least squares models are used to examine relationships between the major ions and discharge, and between pH, colour, temperature, dissolved oxygen, filterable and non filterable residue. Log-transformed data (in this case) provide a better-fit



1 Melaleuca Creek
2 Louisa River
3 Adam River
4 Weld River
5 Sandfly Creek
6 Little Florentine River
7 Huon River
8 Picton River
9 Styx River
10 Savage River
11 Farm Creek
12 Bulgobac Creek
13 Fossey River
14 Hatfield River
15 Waratah Creek
16 Que River
17 Henty River
18 Macintosh River
19 Yollande River
20 Murchison River
21 Whyte River
22 King River
23 Iris River
24 Weaning Paddock Creek
25 Ripples Creek
26 Lake River
27 Woods Creek
28 Castra Rivulet
29 Mersey River
30 Maracoopa Creek
31 Meander River
32 Quamby River
33 Rubicon River
34 Saxon's Creek
35 Flowerdale River
36 Big Creek
37 Inglis River
38 Blackfish Creek
39 Wilsons Creek
40 Baulds Creek
41 Cascade River
42 Groom River
43 North George River
44 George River
45 Weld River (N.E.)
46 Story's Creek
47 Aberfoyle Creek
48 Break O'Day River
49 South Esk River (Mathinna)
50 South Esk River (Perth)
51 Sheepwash Creek
52 Ringarooma River
53 Forester River
54 Brid River
55 St. Patricks River
56 Distillery Creek
57 Blue Tier Creek
58 Clyde River
59 Lisdillon River
60 Apsley River
61 Mountain River
62 Russell River
63 Sandfly Rivulet
64 North West Bay River
65 Creek at Half Moon Bay
66 Dover River
67 Brumbys Creek
*68 Coal River
69 Deep Creek
*70 Derwent River
71 Fisher River
*72 Forth River
*73 George River
74 Gordon River
*75 Great Forester River
*76 Henty River
*77 Huon River
78 Meander River
*79 Mersey River
*80 North Esk River
*81 Pet River
*82 Prosser River
*83 South Esk
84 St. Patricks River
85 Swan River
86 Apsley River

Fig. 16. Location of the 86 water chemistry stations. Rivers marked with an asterisk (circled on map) were used in the temporal survey

regression between discharge and non filterable residue than non-transformed data (Janson 1985, Haworth and Vincent 1982). A log-normal least squares model is used for filterable residue.

The results are compared with other regions in Australia and the northern hemisphere in section 2.3.4.

Results

The mean, range and standard deviation of anions, cations, filterable residue, non filterable residue, pH, dissolved oxygen, colour and temperature for the 12 stations are presented in table 3. Temporal changes of these parameters in relation to discharge are illustrated and tabulated in figures 17 to 28 for stoichiometry, and graphed in figures 29 to 40 for other chemical attributes.

a) Stoichiometry

The Coal and Prosser Rivers fall within hydrological group 2, and have chloride dominated waters (table 3, fig 17, fig 18). Figure 17 demonstrates that increasing discharge produces a change from chloride to bicarbonate dominance, and a corresponding trend away from seawater stoichiometry. The same pattern emerges for the Prosser River, which tends towards increased sodium-bicarbonate dominance with heavy river flows ($Na^+ > Ca^{2+} > Mg^{2+} > K^+$: $Cl^- > HCO_3^- > SO_4^{2-}$ to $Na^+ > Ca^{2+} > Mg^{2+} > K^+$: $HCO_3^- > Cl^- > SO_4^{2-}$). Significant log-transformed regressions indicate consistency of change of the major ions, for both the Prosser and Coal Rivers (fig 17, 18). The increase in bicarbonate ions is probably due to groundwater inputs.

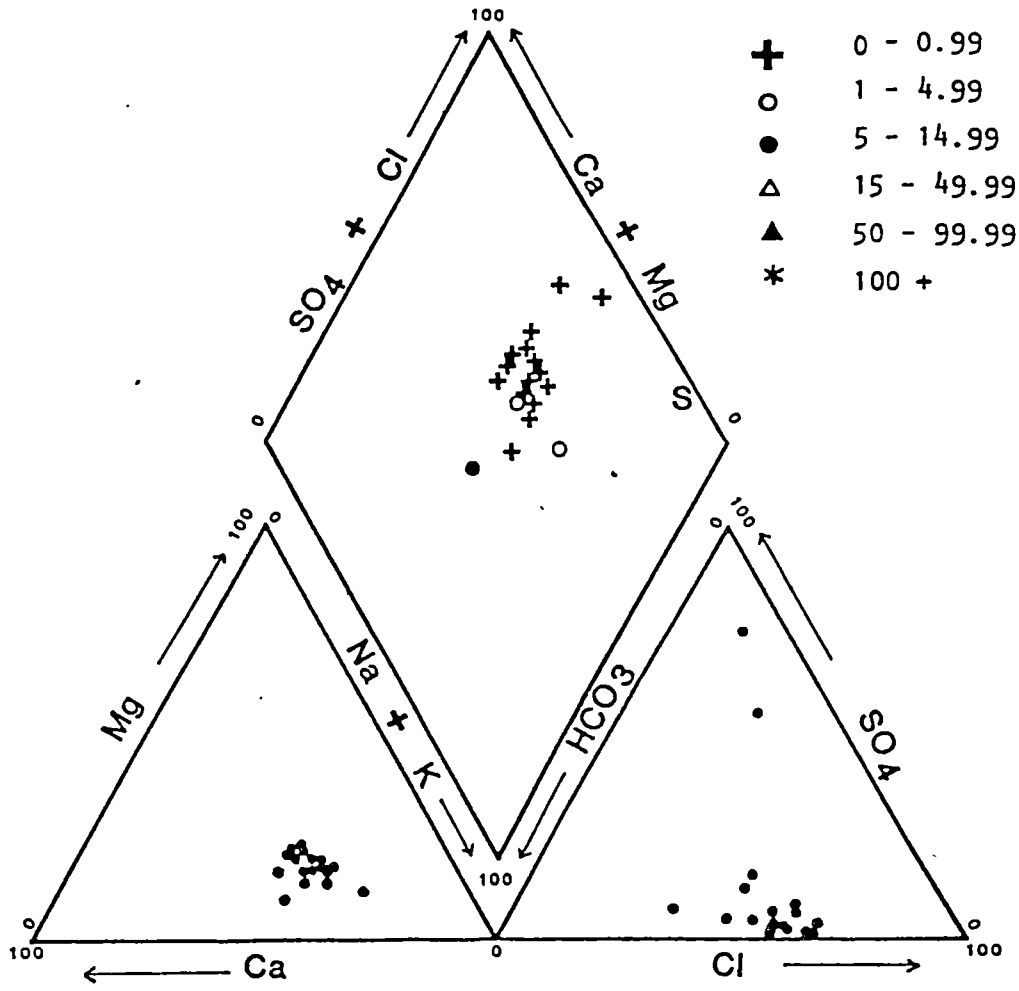
In contrast are the bicarbonate dominated waters of the Pet and North Esk Rivers (hydrological group 4), with stoichiometry of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$: $HCO_3^- > Cl^- > SO_4^{2-}$ (table 3, Fig 19, Fig 20). During high flows the water chemistry of the Pet River tends towards slight chloride enrichment (fig 19). No predictable pattern in stoichiometry is evident for the North Esk River during increasing flows. In general both

	Sodium	Magnesium	Calcium	Potassium	Chloride	Sulphate	Bicarbonate
	(all mg L^{-1})						
Coal River N= (8.1.75-3.10.84)	18	18	18	18	18	18	18
$\bar{X}$	17	30	50	2.1	186.8	21.3	109.3
S_n	39	20	32.7	0.52	139	23.4	68.7
Range	12-134	2.9-70	7.1-120	1.2-3	9-459	5-112	4.8-241
Derwent River N= (27.2.74-14.8.84)	10	10	10	10	10	10	10
$\bar{X}$	4.25	1.55	3.46	0.32	8.06	0.98	19.6
S_n	0.55	0.56	2.06	0.14	1.76	0.81	2.69
Range	3.8-5.5	0.1-2.2	0.1-8.8	0.2-0.6	5.3-11	0.2-1.8	15-23
Forth River N= (27.2.74-25.10.84)	10	10	10	10	10	10	10
$\bar{X}$	2.63	0.79	2	0.23	4.03	0.7	8.17
S_n	0.32	0.35	0.59	0.06	1.02	0.34	4.36
Range	2-3	0.2-1.5	1.4-3.4	0.16-0.35	2.6-5.9	0.1-1.0	2.6-20
George River N= (27.2.74-28.8.84)	11	11	11	11	11	11	11
$\bar{X}$	8.46	1.17	2.52	0.88	14.3	1.75	10
S_n	0.99	0.53	0.87	0.18	2.82	0.53	2.17
Range	7.2-10	0.09-2.1	1.7-5.0	0.64-1.3	12-20	1.1-3.1	6.5-14
Great Forester N= River (27.2.74-28.8.84)	11	11	11	11	11	11	11
$\bar{X}$	8.5	1.5	2.7	1	15.1	2.2	9.7
S_n	2.4	0.56	0.8	0.35	4.9	1.01	3.7
Range	4.3-11	0.4-2.6	1.6-4.0	0.6-1.7	5.3-21	0.4-3.6	3-15
Henty River N= (27.2.74-22.5.84)	19	19	19	19	19	19	19
$\bar{X}$	4.7	1.15	2.4	0.3	18.2	1.3	14.5
S_n	1.47	0.59	1.8	0.13	38.5	0.61	29
Range	0.2-6.7	0.5-2.8	0.8-8.8	0.1-0.6	5.2-181	0.2-4.4	1.6-136
Huon River N= (27.2.74-15.8.84)	9	9	9	9	9	9	9
$\bar{X}$	4.28	1.8	5.6	0.3	8.7	1.16	13.8
S_n	1.42	0.67	2.66	0.06	1.4	0.48	5.2
Range	4.0-5.4	0.5-3.1	1.7-9.8	0.2-0.38	5.6-9.9	0.4-2	7.8-24
Mersey River N= (22.8.74-28.8.84)	10	10	10	10	10	10	10
$\bar{X}$	19.6	5	23.3	1.12	37	5.3	72.7
S_n	22.3	2.6	14.6	0.82	43.7	6.0	30.7
Range	4.7-78	1.9-9.4	2.7-50	0.7-3.3	7.8-156	0.4-22	28-119
North Esk River N= (27.2.74-3.8.84)	11	11	11	11	11	11	11
$\bar{X}$	5	1.9	4	0.53	7.1	0.84	18
S_n	0.67	0.3	0.7	0.11	1.03	0.23	3.3
Range	4-5.8	1.3-2.2	3-5.2	0.36-0.8	5-8.5	0.4-1.3	11-23
Pet River N= (27.2.74-29.8.84)	11	11	11	11	11	11	11
$\bar{X}$	5.5	2.48	2.29	0.66	8.8	1.27	19
S_n	2	0.64	0.92	0.18	1.61	0.67	4.65
Range	0.56-8.3	1.3-3.6	2.2-4.6	0.4-0.95	5.7-12	0.4-2.9	13-28
Prosser River N= (27.2.74-14.8.84)	11	11	11	11	11	11	11
$\bar{X}$	16.1	9.4	18.3	1.3	80.2	4.3	50.6
S_n	20.9	6.1	14.1	0.47	65.3	2.4	26.4
Range	3.5-75	2.3-20	4.4-55	0.82-2.3	12-169	2.7-9.9	12-109
South Esk River N= (27.2.74-29.8.84)	11	11	11	11	11	11	11
$\bar{X}$	4.2	3.2	3.9	0.57	16	3.2	22
S_n	4.0	1.1	1.6	0.18	4.9	2	7.6
Range	2.6-11	0.97-4.9	2-7.6	0.27-0.9	3.4-22	1-9	11-38

Table 3. Summary statistics for each of the physical-chemical variables used in the temporal survey

	Temperature °C	pH	Dissolved Oxygen ($mg\ l^{-1}$)	Colour (hazen units)	Non filterable residue ($mg\ l^{-1}$)	Filterable residue ($mg\ l^{-1}$)
Coal River N= (8.1.75-3.10.84)	97	103	88	102	103	103
$\bar{X}$	11.38	7.9	10.6	46	11.6	716
S_n	5.08	0.41	1.68	47	18.3	502
Range	2-23	6.6-8.9	6.2-14	5-250	1-100	120-2880
Derwent River N= (27.2.74-14.8.84)	38	41	38	40	41	42
$\bar{X}$	10.8	7.2	10.14	35.6	4	56.62
S_n	4.8	1.1	1.59	22.7	4.49	25.3
Range	3.5-21	6.6-8.3	7.5-12	5-85	0.4-17	36-205
Forth River N= (27.2.74-25.10.84)	37	39	33	38	38	39
$\bar{X}$	11.5	7	9.4	35.3	3.9	34.6
S_n	4.6	0.51	2.1	20.7	7.3	17.3
Range	4.5-18	5.4-7.8	7.4-12	10-125	0.4-44	7-100
George River N= (27.2.74-28.8.84)	41	43	36	40	42	43
$\bar{X}$	11.4	7	9.6	48.9	22.9	60.25
S_n	4.6	0.37	2.14	29.6	65	17.32
Range	3.5-21	6.2-7.7	8-12	15-150	1-435	4.8-93
Great Forester River N= (27.2.74-28.8.84)	41	43	35	41	42	43
$\bar{X}$	10.5	6.9	9.9	56	16	62.7
S_n	3.9	0.34	1	35	19	17.7
Range	4-19	6.1-7.6	7.4-12	5-125	0.4-92	25-102
Henty River N= (27.2.74-22.5.84)	70	88	75	86	87	87
$\bar{X}$	9.3	6.8	10.7	76.2	4	52.3
S_n	3.4	0.7	1.2	29.8	5.6	17.5
Range	2-17	5.2-8.4	8-15	9-150	0.4-27	17-133
Huon River N= (27.2.74-15.8.84)	41	42	37	39	40	42
$\bar{X}$	8.9	7.3	10	130.4	4.81	76.5
S_n	4.4	0.5	1.22	42.5	8.6	28.5
Range	4-19	6.3-8.3	7.3-12	50-240	0.4-54	42-202
Mersey River N= (22.8.74-28.8.84)	42	43	38	42	42	43
$\bar{X}$	13.3	7.8	10.2	41.3	7.6	167
S_n	5.6	0.41	1.18	38.7	10.8	152
Range	6-25	6.9-8.4	7.9-12	5-140	1-51	78-300
North Esk River N= (27.2.74-3.8.84)	42	44	37	42	43	44
$\bar{X}$	10.1	7.3	10.3	29.3	10	30.2
S_n	4.7	0.38	1.8	23.2	14.0	35.9
Range	3-17	6.6-8.4	2-12	5-100	1-87	22-263
Pet River N= (27.2.74-29.8.84)	41	43	36	42	42	43
$\bar{X}$	11.14	7.23	10	20.4	6.2	52.9
S_n	3.6	0.36	0.87	10.5	8.2	17.44
Range	7-20	6.4-7.8	8-11	5-50	0.4-45	26-125
Prosser River N= (27.2.74-14.8.84)	39	44	34	42	43	44
$\bar{X}$	11.9	7.5	9.9	89.6	10.0	267
S_n	5.4	0.5	1.7	64.9	17.7	108
Range	4-23	6.3-8.3	6.2-13	5-300	0.2-97	52-532
South Esk River N= (27.2.74-29.8.84)	41	43	35	41	42	43
$\bar{X}$	12.7	7.2	9.8	30.8	5.4	74.3
S_n	5.6	0.3	1.3	29.2	8.7	24.3
Range	5-22	6.6-7.8	8-12	5-125	1-53	24-141

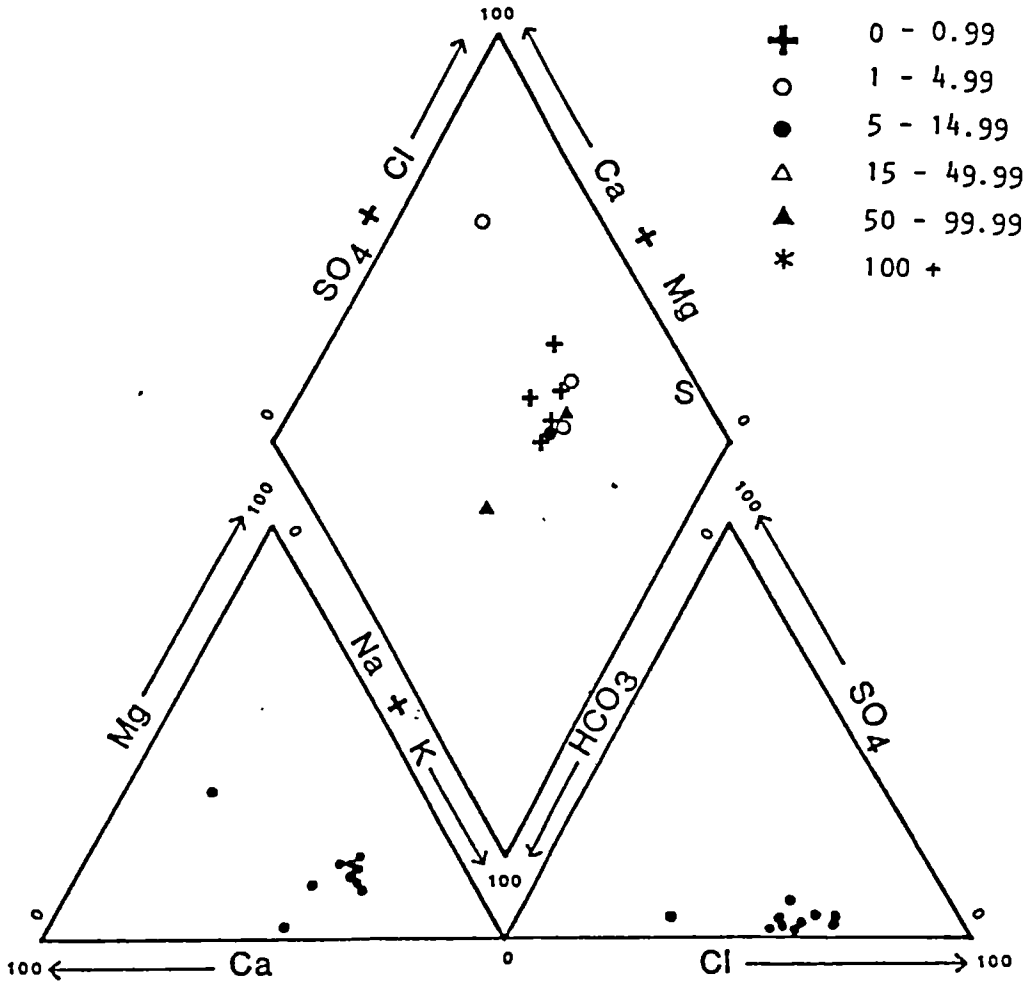
Table 3. (continued)



Coal River	Regression equation	r	significance %
HCO_3^-	logY = 1.71 - 0.23 logX	-0.43	0.1
Cl^-	logY = 1.82 - 0.36 logX	-0.6	0.01
SO_4^{2-}		0.07	
Na^+	logY = 1.52 - 0.32 logX	-0.8	0.001
K^+	logY = 0.24 - 0.1 logX	-0.75	0.001
Ca^{2+}	logY = 1.37 - 0.31 logX	-0.73	0.001
Mg^{2+}	logY = 1.05 - 0.38 logX	-0.75	0.001

Y = concentration, X = discharge

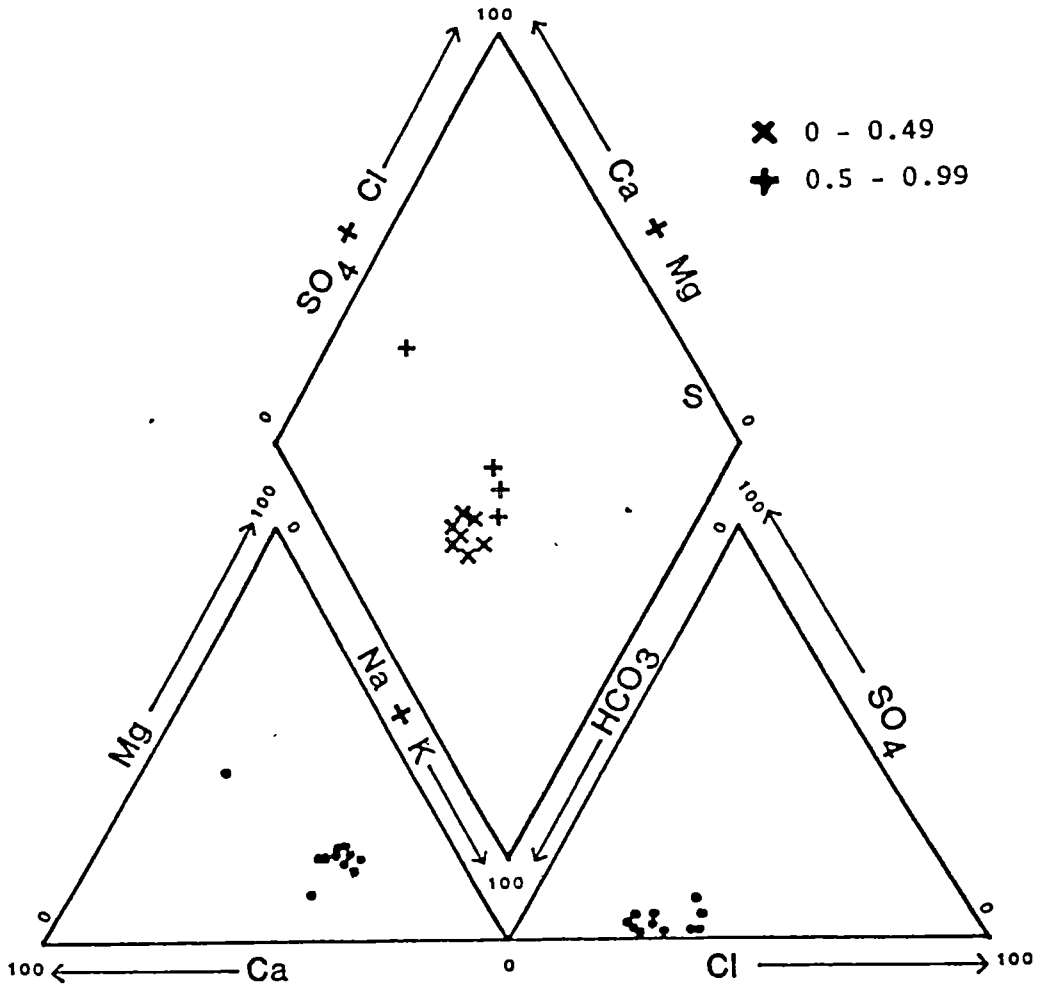
Fig. 17. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Coal River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Prosser River	Regression equation	r	significance %
HCO_3^-	logY = 1.62 - 0.23 logX	-0.86	0.001
Cl^-	logY = 1.89 - 0.33 logX	-0.91	0.001
SO_4^{2-}	logY = 0.64 - 0.17 logX	-0.73	0.01
Na^+	logY = 1.43 - 0.28 logX	-0.67	0.02
K^+	logY = 0.12 - 0.08 logX	-0.51	0.1
Ca^{2+}	logY = 1.22 - 0.32 logX	-0.91	0.001
Mg^{2+}	logY = 0.91 - 0.25 logX	-0.66	0.02

Y = concentration, X = discharge

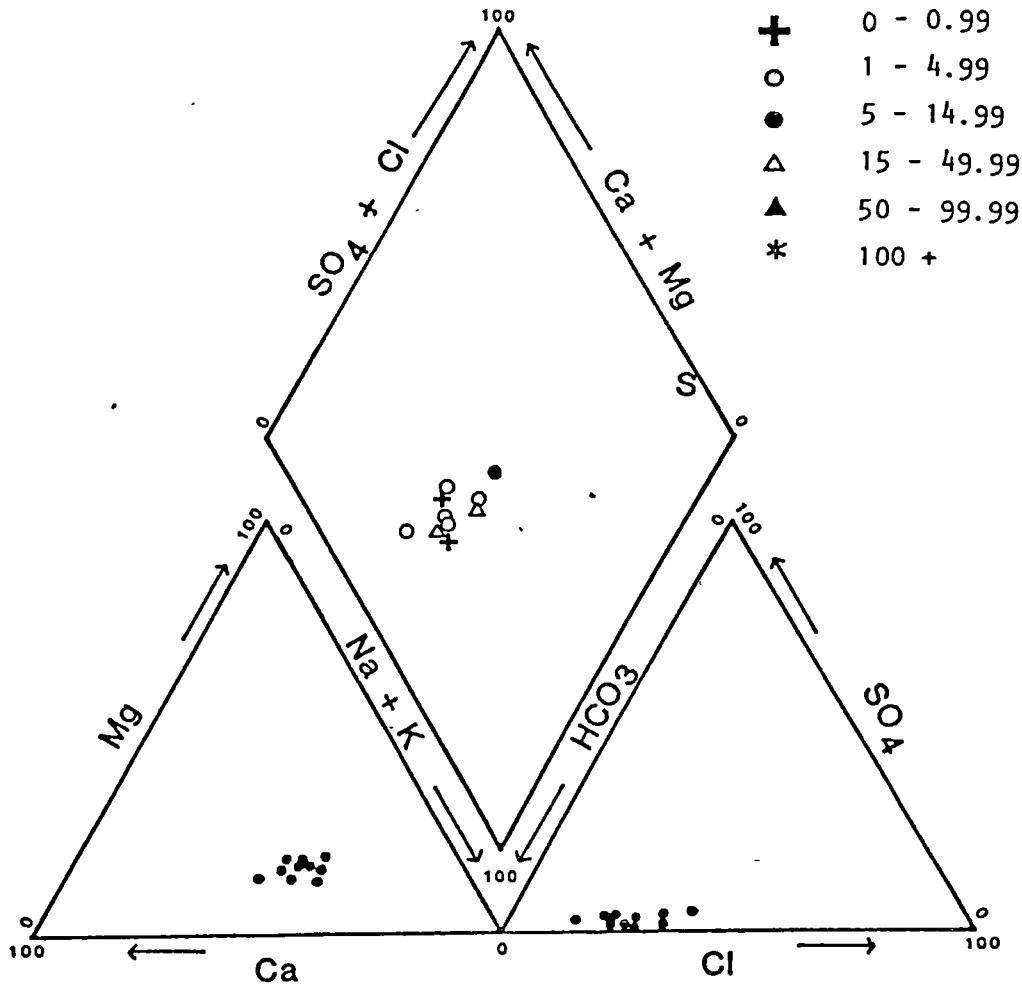
Fig. 18. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Prosser River. Each point is plotted as a % of total cation or anion concentration in mg L^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Pet River	Regression equation	r	significance %
HCO_3^-	logY = 1.13 - 0.2 logX	-0.94	0.001
Cl^-		0.43	
SO_4^{2-}		0.09	
Na^+		0.43	
K^+	logY = -0.3 - 0.15 logX	-0.62	0.05
Ca^{2+}	logY = 0.43 - 0.12 logX	-0.6	0.05
Mg^{2+}	logY = 0.24 - 0.2 logX	-0.81	0.001

Y = concentration, X = discharge

Fig. 19. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Pet River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}.; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



North Esk River	Regression equation	r	significance %
HCO_3^-	logY = 1.33 - 0.14 logX	-0.75	0.01
Cl^-		0.31	
SO_4^{2-}		0.2	
Na^+		0.42	
K^+		0.02	
Ca^{2+}	logY = 0.65 - 0.1 logX	-0.61	0.05
Mg^{2+}	logY = 0.33 - 0.12 logX	-0.76	0.01

Y = concentration, X = discharge

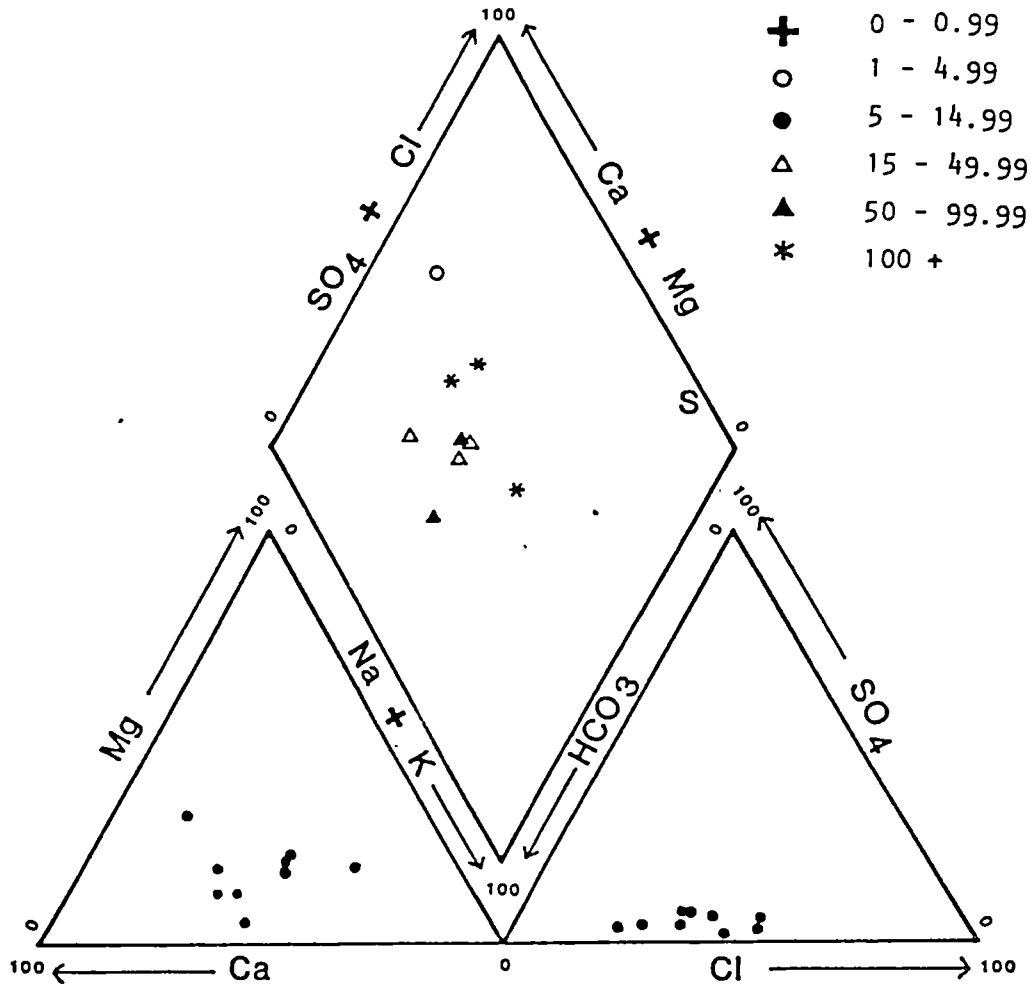
Fig. 20. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the North Esk River. Each point is plotted as a % of total cation or anion concentration in mg L^{-1}.; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below

rivers display little variation in stoichiometry, despite the variable discharges. The least square regressions demonstrate significant correlations between bicarbonate, calcium and magnesium with discharge for both rivers, as well as potassium for the Pet River.

Variation in stoichiometry is displayed for the Huon and Henty Rivers (fig 21, fig 22). These rivers, together with the Forth and Derwent are to be found in hydrological group 3. During high flows (> 100 cumecs) the water chemistry of the Huon River shifts away from a calcium bicarbonate stoichiometry, though there is little consistency of chemistry with varying discharge. Only sulphate and sodium vary significantly with discharge (fig 21). Changes in ionic configuration of the Henty River vary from sodium bicarbonate predominance during low flows to sodium chloride dominance during high discharges. This pattern is reflected in the regression equations, where bicarbonate changes inversely with discharge, as well as calcium and magnesium. Stoichiometry of the Henty River closely resembles that of seawater for flows greater than 15 cumecs.

The Forth River (fig 23) displays bicarbonate dominance for all discharges, with the exception of outlying sample ●. This sample was obtained during a rise in discharge in summer after a prolonged dry period, which may account for the chloride enrichment. There is little consistency of stoichiometry with discharge, which is reflected in the least squares equations. Sodium, alone, varies significantly with discharge. The Derwent River tends from calcium carbonate stoichiometry towards slight sodium predominance for flows greater than 100 cumecs (fig 24).

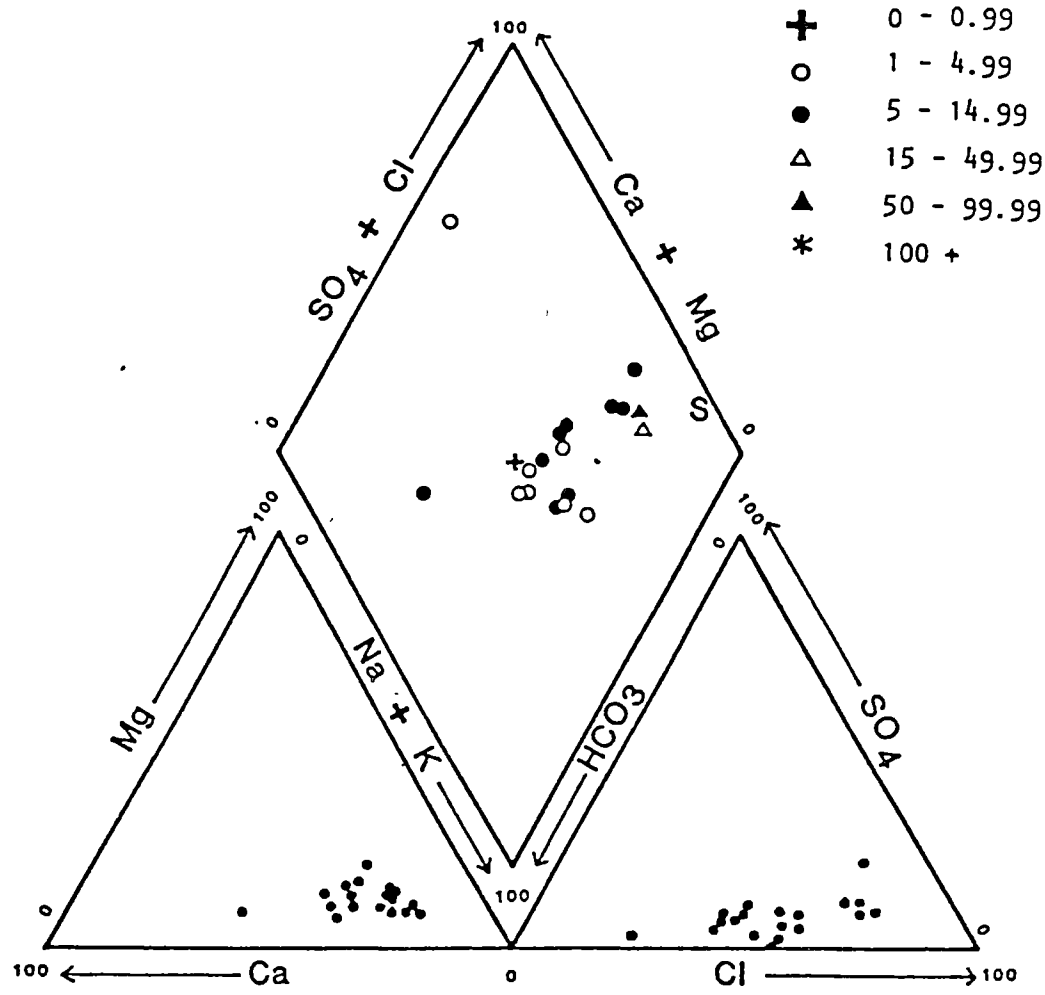
The South Esk River (fig 25), falls within hydrological group 1, and displays little consistency of stoichiometric change with increasing discharge. The regression equations confirm the lack of relationship between discharge and ions. This lack of pattern contrasts with the Great Forester River (fig 26) which displays a marked tendency towards seawater



Huon River	Regression equation	r	significance %
HCO_3^-		1.12	
Cl^-		0.26	
SO_4^{2-}	$\log Y = 0.43 - 0.24 \log X$	-0.57	0.1
Na^+	$\log Y = -0.23 + 0.23 \log X$	0.74	0.01
K^+		0.37	
Ca^{2+}		0.15	
Mg^{2+}		0.21	

Y = concentration, X = discharge

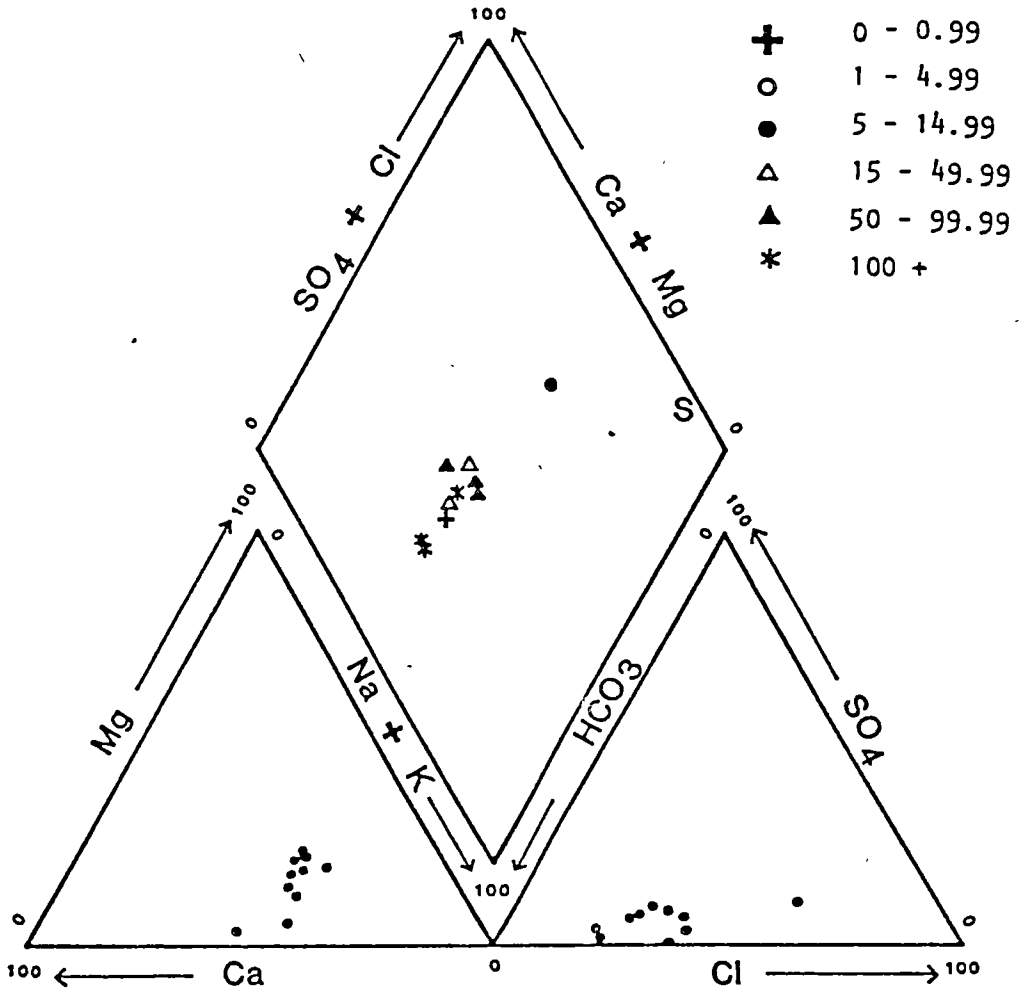
Fig. 21. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Huon River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Henty River	Regression equation	r	significance %
HCO_3^-	logY = 1.18 - 0.49 logX	-0.51	0.02
Cl^-		0.18	
SO_4^{2-}		0.14	
Na^+		0.15	
K^+		0.28	
Ca^{2+}	logY = 0.52 - 0.31 logX	-0.59	0.01
Mg^{2+}	logY = 0.21 - 0.28 logX	-0.65	0.01

Y = concentration, X = discharge

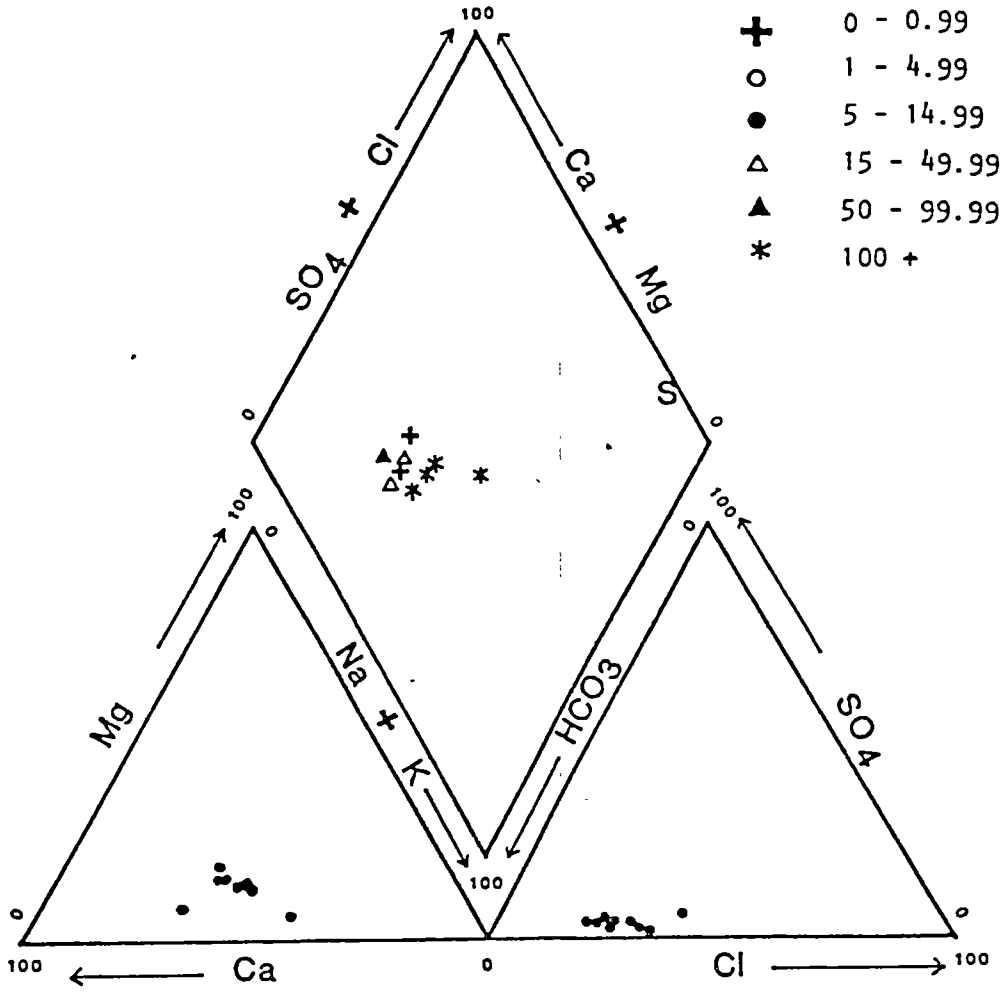
Fig. 22. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Henty River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}.; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Forth River	Regression equation	r	significance %
HCO_3^-		0.12	
Cl^-		0.08	
SO_4^{2-}		0.44	
Na^+	$\log Y = 0.45 - 0.04 \log X$	-0.53	0.1
K^+		0.003	
Ca^{2+}		0.21	
Mg^{2+}		0.12	

Y = concentration, X = discharge

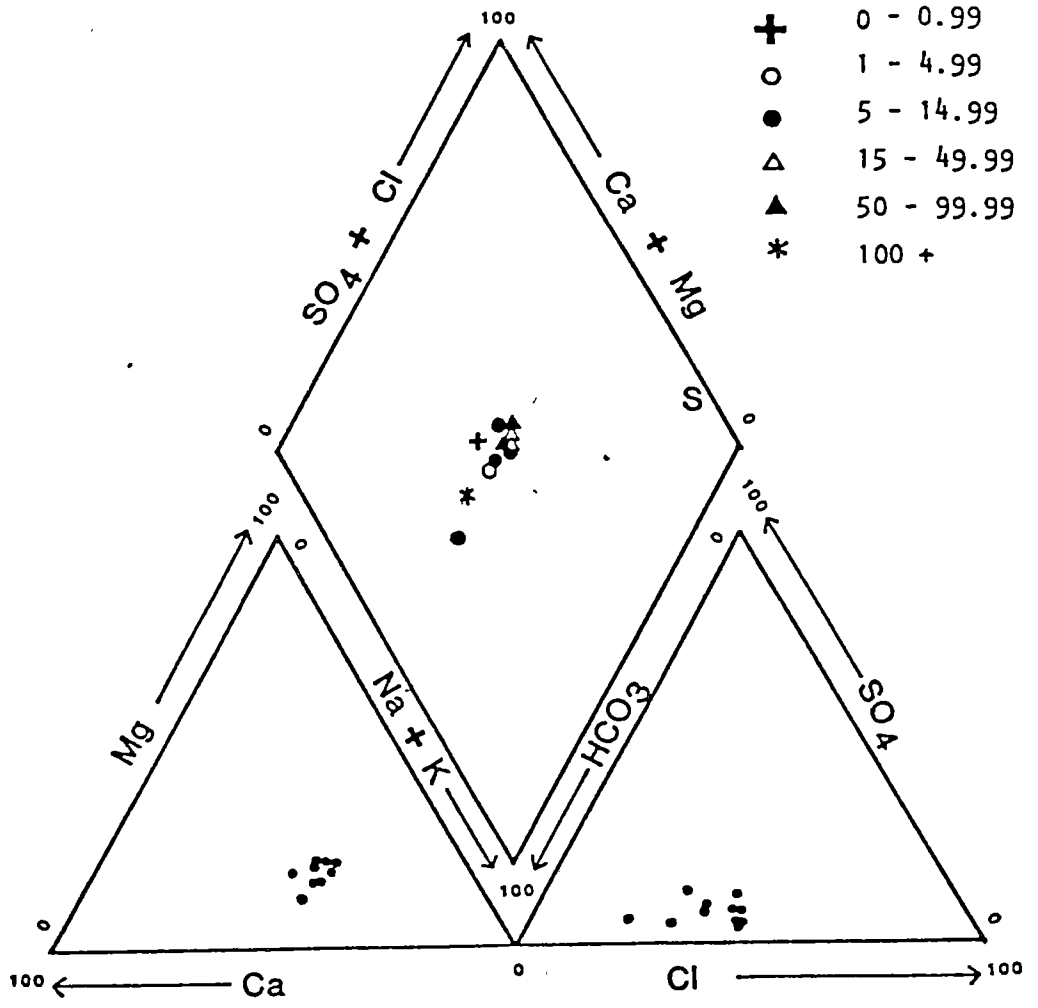
Fig. 23. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Forth River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}.; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Derwent River	Regression equation	r	significance %
HCO_3^-	logY = 1.44 - 0.08 logX	-0.55	0.1
Cl^-		0.04	
SO_4^{2-}		0.1	
Na^+		0.45	
K^+	logY = -1.3 + 0.39 logX	0.7	0.02
Ca^{2+}		0.25	
Mg^{2+}		0.24	

Y = concentration, X = discharge

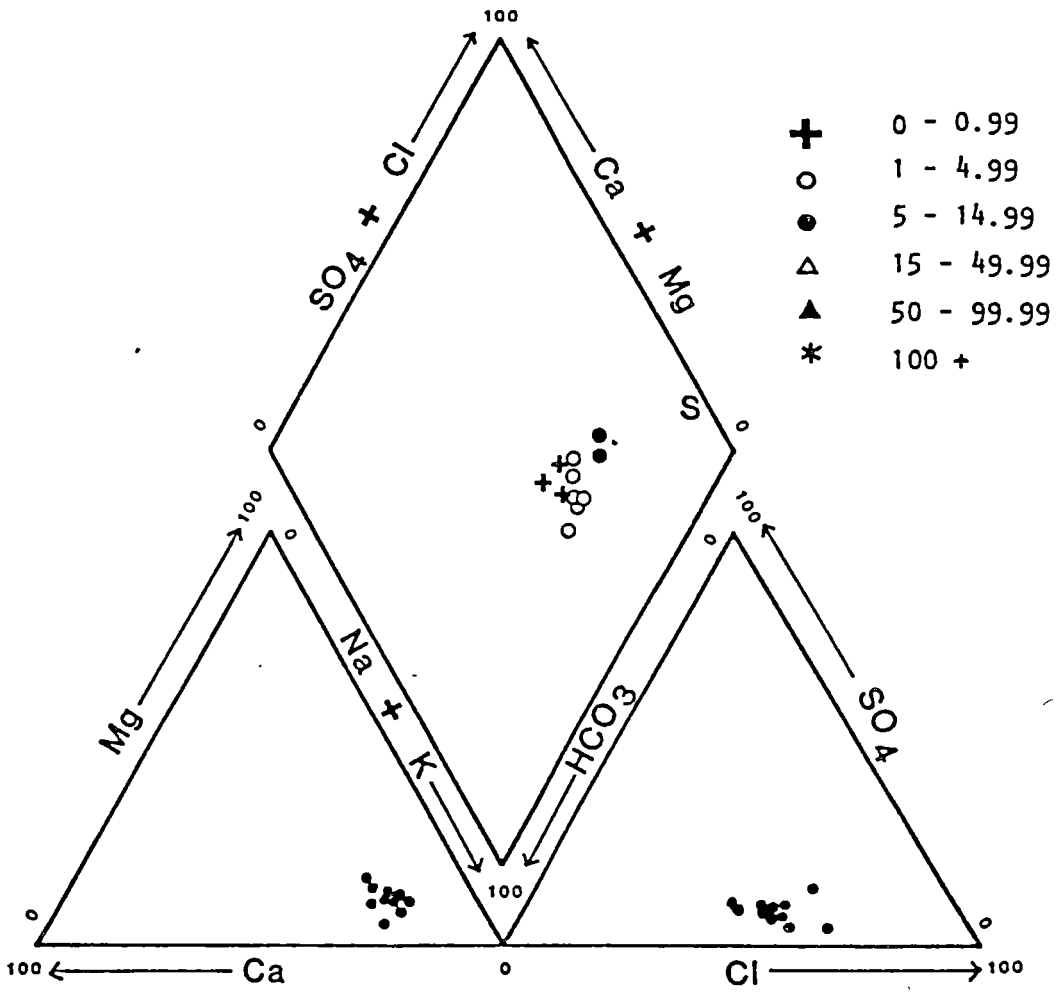
Fig. 24. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Derwent River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1} ; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



South Esk	Regression equation	r	significance %
HCO_3^-		0.007	
Cl^-		0.17	
SO_4^{2-}		0.18	
Na^+		0.22	
K^+		0.47	
Ca^{2+}		0.27	
Mg^{2+}		0.03	

Y = concentration, X = discharge

Fig. 25. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the South Esk River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Great Forester	Regression equation	r	significance %
HCO_3^-		0.45	
Cl^-		0.28	
SO_4^{2-}	logY = 0.43 - 0.45 logX	-0.53	0.1
Na^+	logY = 0.99 - 0.24 logX	-0.53	0.1
K^+	logY = 0.09 - 0.27 logX	-0.57	0.05
Ca^{2+}	logY = 0.47 - 0.2 logX	-0.48	0.1
Mg^{2+}	logY = 0.29 - 0.43 logX	-0.65	0.02

Y = concentration, X = discharge

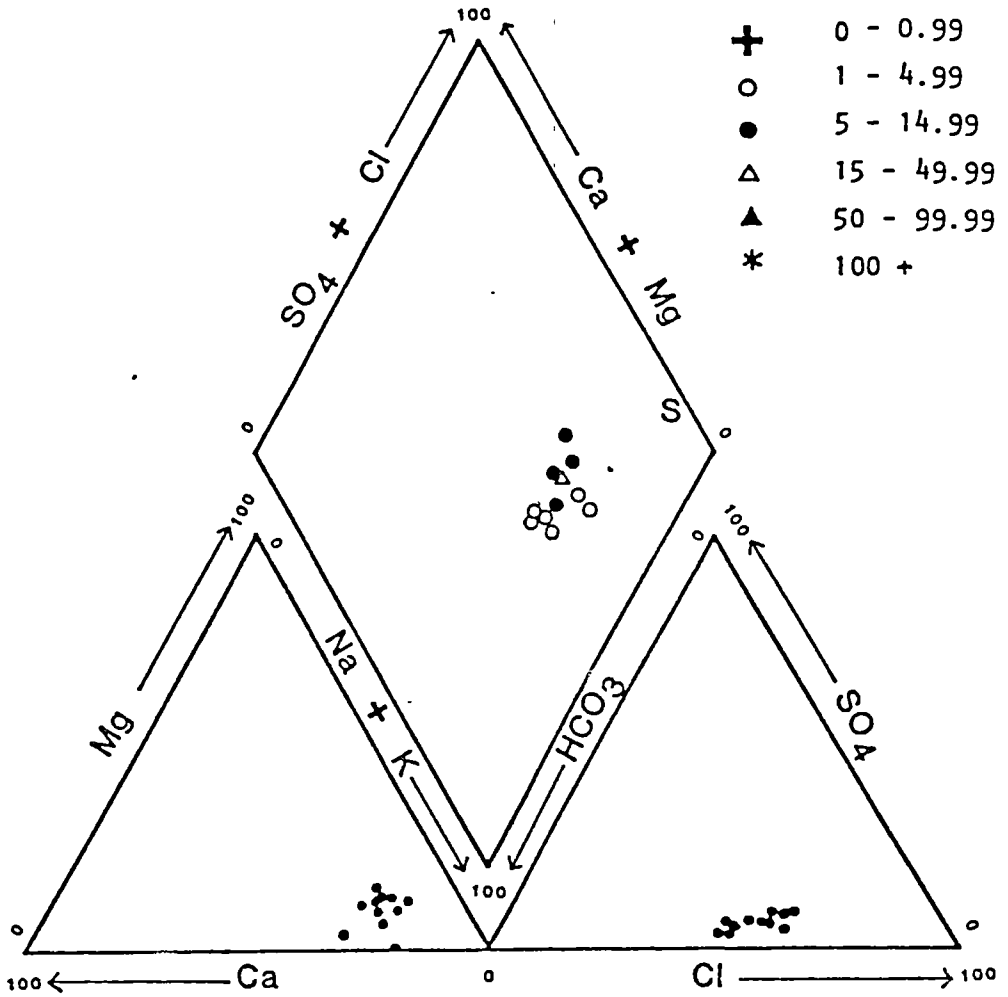
Fig. 26. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Great Forester River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below

stoichiometry. The George River displays a less dramatic tendency (fig 27). Although these rivers belong to hydrological group 1, their stoichiometry more closely resembles that of the Prosser and Coal Rivers. This probably reflects high precipitation : evaporation ratios for the north-east of Tasmania. However, contrary to the Coal and Prosser Rivers, the George and Great Forester Rivers shift towards chloride dominance with increasing discharge, reflecting precipitation dominated ions. The Mersey River (fig 28) displays a wide variation in stoichiometry. Calcium carbonate dominance occurs for discharges of 5-15 cumecs, while flows greater than 50 cumecs tend away from this configuration. The equations (fig 28) demonstrate negative correlations for bicarbonate, sodium and calcium with discharge.

The results demonstrate wide variation of stoichiometry and inconsistency of change with discharge, both within and between catchments. The most consistently changing rivers, the Coal and Prosser, are situated in the part of the state experiencing the greatest variation of discharge. The results further emphasize the caution needed to be exercised when interpreting water chemistry data obtained on a one-off or occasional basis. However, within this range of variation, it is possible to distinguish discrete stoichiometric groups eg. sodium chloride for the George River, calcium bicarbonate for the Derwent River. Deviations from these broad chemical groups are usually experienced during unusual hydrological events such as peak flows, or rising flows after a dry period. Lotic waters in Tasmania do appear to be enriched in bicarbonate ions relative to lentic waters, which is contrary to the conclusions of Buckney and Tyler (1973) that most waters in Tasmania have seawater stoichiometry.

b) Other chemical attributes

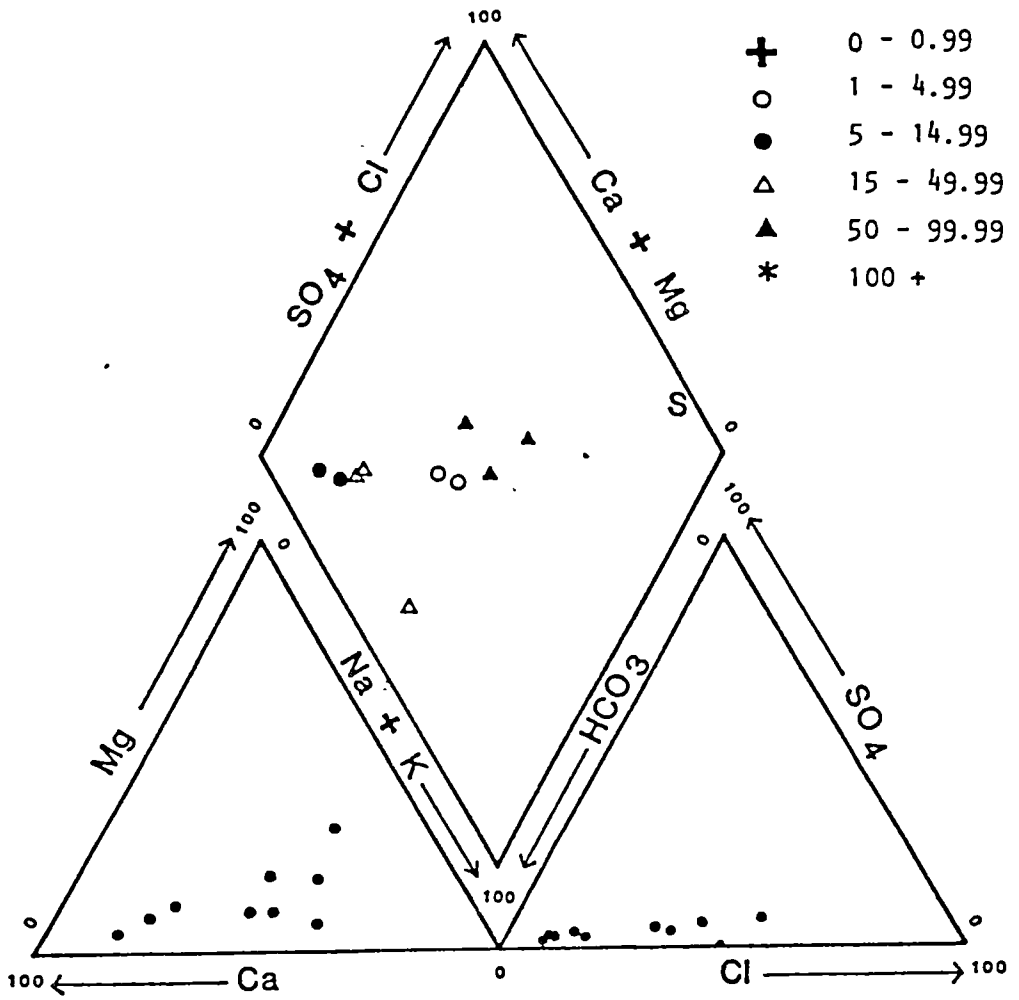
Relationships were examined for the 12 rivers between pH and colour, dissolved oxygen and temperature, filterable and non filterable residue and discharge. The mean, range and



George River	Regression equation	r	significance %
HCO_3^-	logY = 1.2 - 0.27 logX	-0.87	0.001
Cl^-		0.22	
SO_4^{2-}		0.23	
Na^+		0.29	
K^+		0.08	
Ca^{2+}		0.13	
Mg^{2+}	logY = 0.48 - 0.6 logX	-0.57	0.05

Y = concentration, X = discharge

Fig. 27. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the George River. Each point is plotted as a % of total cation or anion concentration in mg L^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below



Mersey River	Regression equation	r	significance %
HCO_3^-	logY = 2.18 - 0.33 logX	-0.93	0.001
Cl^-		0.35	
SO_4^{2-}		0.49	
Na^+	logY = 1.39 - 0.29 logX	-0.53	0.1
K^+		0.21	
Ca^{2+}	logY = 1.69 - 0.45 logX	-0.71	0.05
Mg^{2+}		0.31	

Y = concentration, X = discharge

Fig. 28. Ternary diagram showing relative proportions of the major ions with changing discharge (cumecs) for the Mersey River. Each point is plotted as a % of total cation or anion concentration in mg l^{-1}; S = seawater. The least squares relationship between major ions and discharge is displayed in the table below

standard deviation of these variables is presented in table 3.

The Coal River (fig 29) displays a significant least squares relationship between temperature and dissolved oxygen ($r = 0.57$, $p < 0.001$), but there appears to be little consistent variation with discharge (discharges >5 cumecs do tend towards lower temperatures and dissolved oxygen). Discharges greater than 1 cumec experience an increase in colour and a decrease in pH, with the least squares relationship between colour and pH being a significant one ($r = 0.67$, $p < 0.001$). There is no significant relationship between discharge and non filterable residue ($r = 0.16$, $p > 0.1$), but there is a negative correlation between discharge and filterable residue ($r = 0.67$, $p < 0.001$). The Coal River experiences the largest range of values of filterable residue for any of the 12 rivers.

Comparisons with the Prosser River (fig 30), indicate similar trends. Colour increases and pH decreases with discharges greater than 1 cumec, and both variables are linearly related ($r = 0.75$, $p < 0.001$). Similarly, dissolved oxygen and temperature are correlated ($r = 0.57$, $p < 0.001$), but again discharge does not appear to consistently alter either of the variables. Non filterable residue, however, is exponentially related to discharge: as discharge increases, quantities of suspended sediment also increase. Figure 30 indicates a negative correlation between discharge and filterable residue ($r = 0.68$, $p < 0.001$), demonstrating how increasing discharge dilutes the concentration of total dissolved solids.

There is no significant correlation between colour and pH for the Pet River (fig 31). Lower discharges do, however, tend to experience lower values for colour. Dissolved oxygen and temperature are predictably correlated ($r = 0.51$, $p < 0.01$), where flows greater than 0.5 cumecs have lower temperatures and higher dissolved oxygen. Non filterable residue has no significant relationship with discharge, but

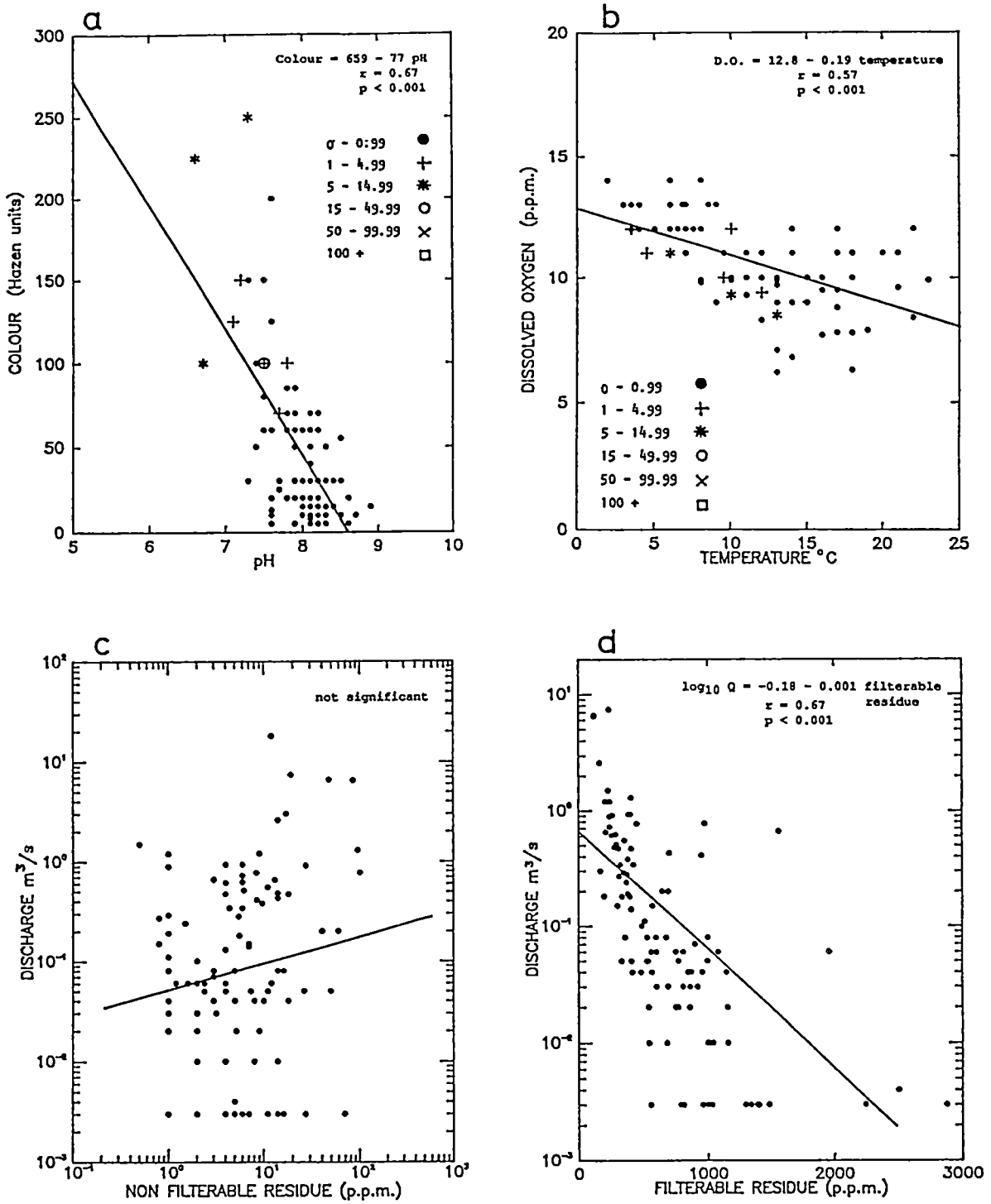


Fig. 29. Least squares relationships for the Coal River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

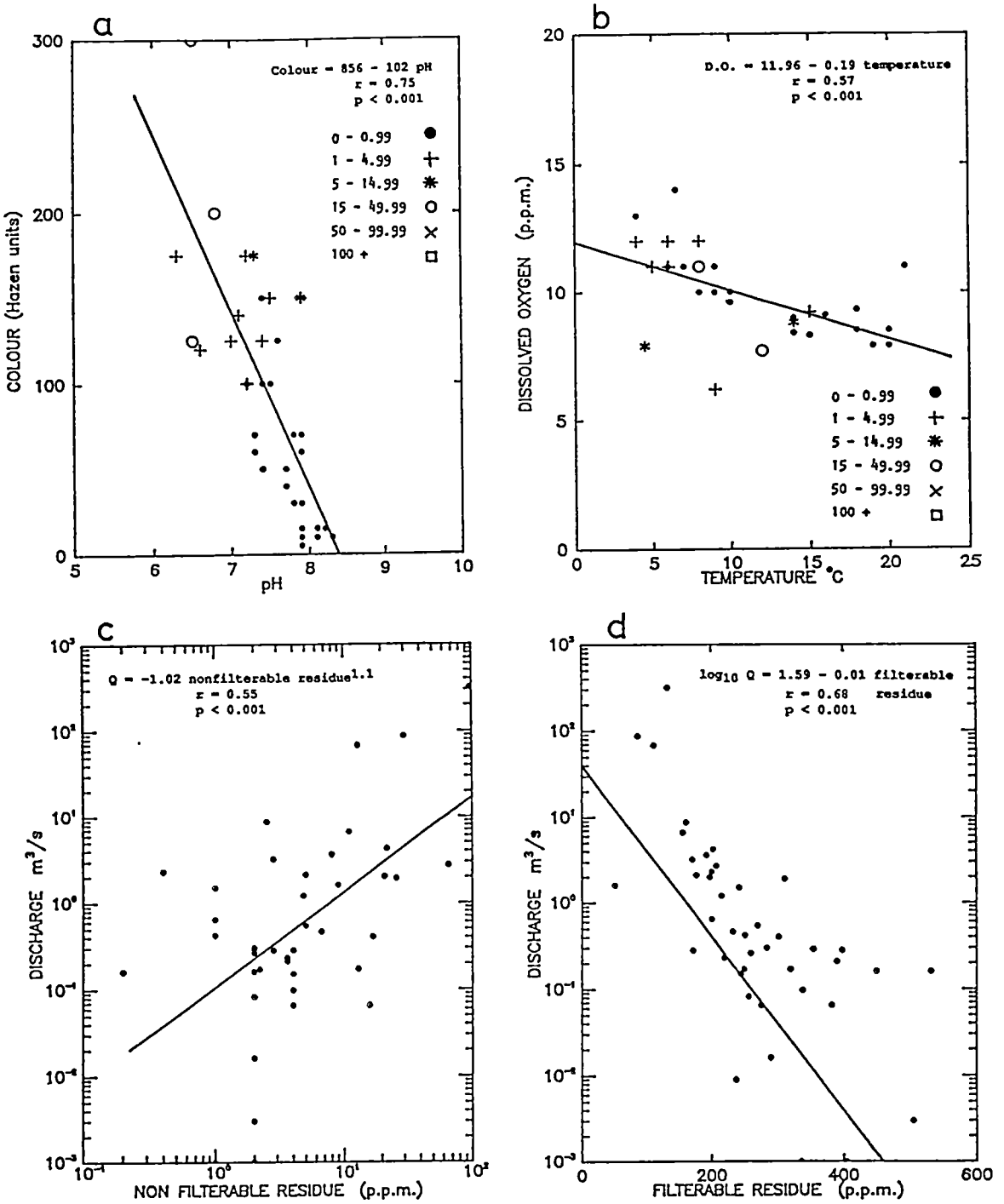


Fig. 30. Least squares relationships for the Prosser River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

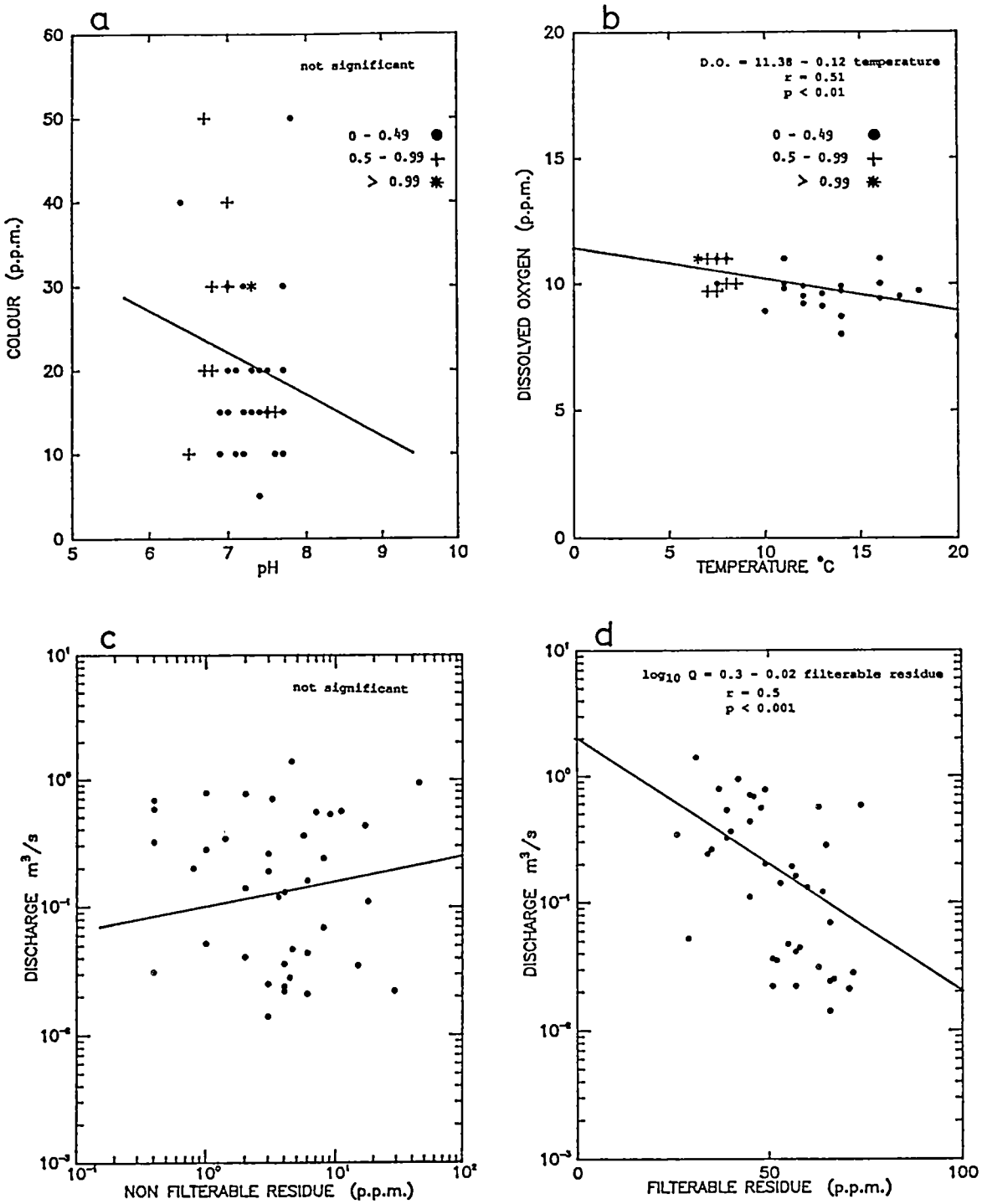


Fig. 31. Least squares relationships for the Pet River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

filterable residue significantly increases as discharge decreases ($r = 0.5$, $p < 0.001$).

The North Esk River is also in hydrological group 4, but displays some incompatible trends (fig 32). Colour and pH are significantly correlated ($r = 0.49$, $p < 0.001$), though there appears to be no relationship with discharge. The relationship between dissolved oxygen and temperature is a strong one ($r = 0.71$, $p < 0.001$), but there are no predictable trends with discharge. Unusually, filterable residue shows no significant correlation with discharge, however non filterable residue has a strong positive relationship ($r = 0.54$, $p < 0.001$).

The following four rivers belong to hydrological group 3, which is composed of rivers in the south and west of Tasmania. There is a significant relationship between pH and colour for the Huon River ($r = 0.45$, $p < 0.1$) (fig 33), which also displays the highest minimum and mean values (50 and 130 hazen units respectively) for colour (table 3). Dissolved oxygen decreases as temperature increases ($r = 0.68$, $p < 0.001$), but no trend is revealed with discharge. There is no significant least squares relationship between discharge and non filterable residue, or between discharge and filterable residue.

Colour and pH for the Henty River are significantly but not strongly correlated (fig 34) ($r = 0.25$, $p < 0.05$), which contrasts with a strong trend between temperature and dissolved oxygen ($r = 0.81$, $p < 0.001$). There appears to be no relationship between these variables and discharge. No correlation exists between discharge and non filterable residue, but a weak relationship is observed between discharge and filterable residue ($r = 0.2$, $p < 0.1$).

Correlations for the Forth River (fig 35) between colour and pH, and between dissolved oxygen and temperature are insignificant ($r = 0.19$, $p > 0.1$) and significant ($r = 0.61$, $p < 0.01$) respectively. Again there is little or no

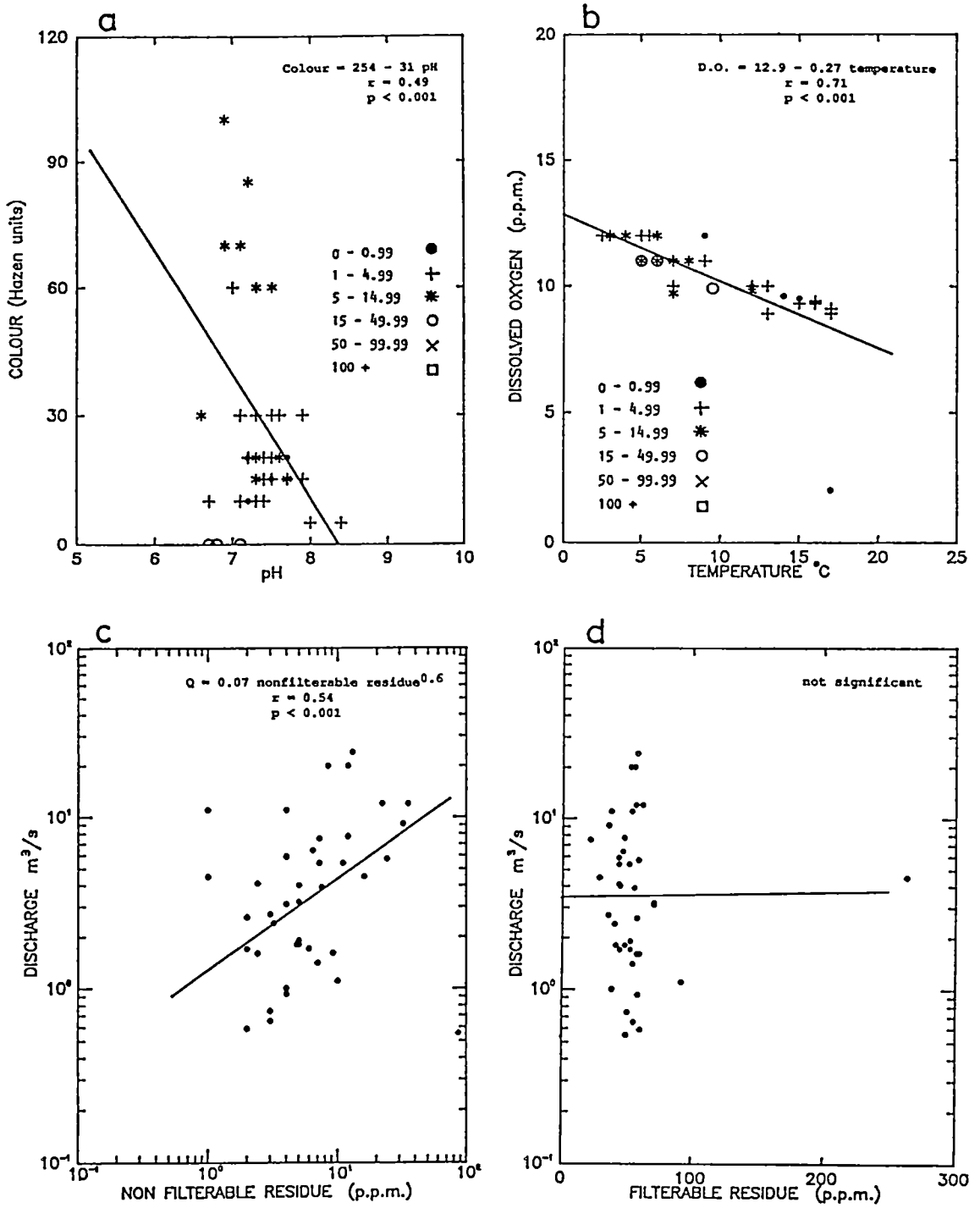


Fig. 32. Least squares relationships for the North Esk River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

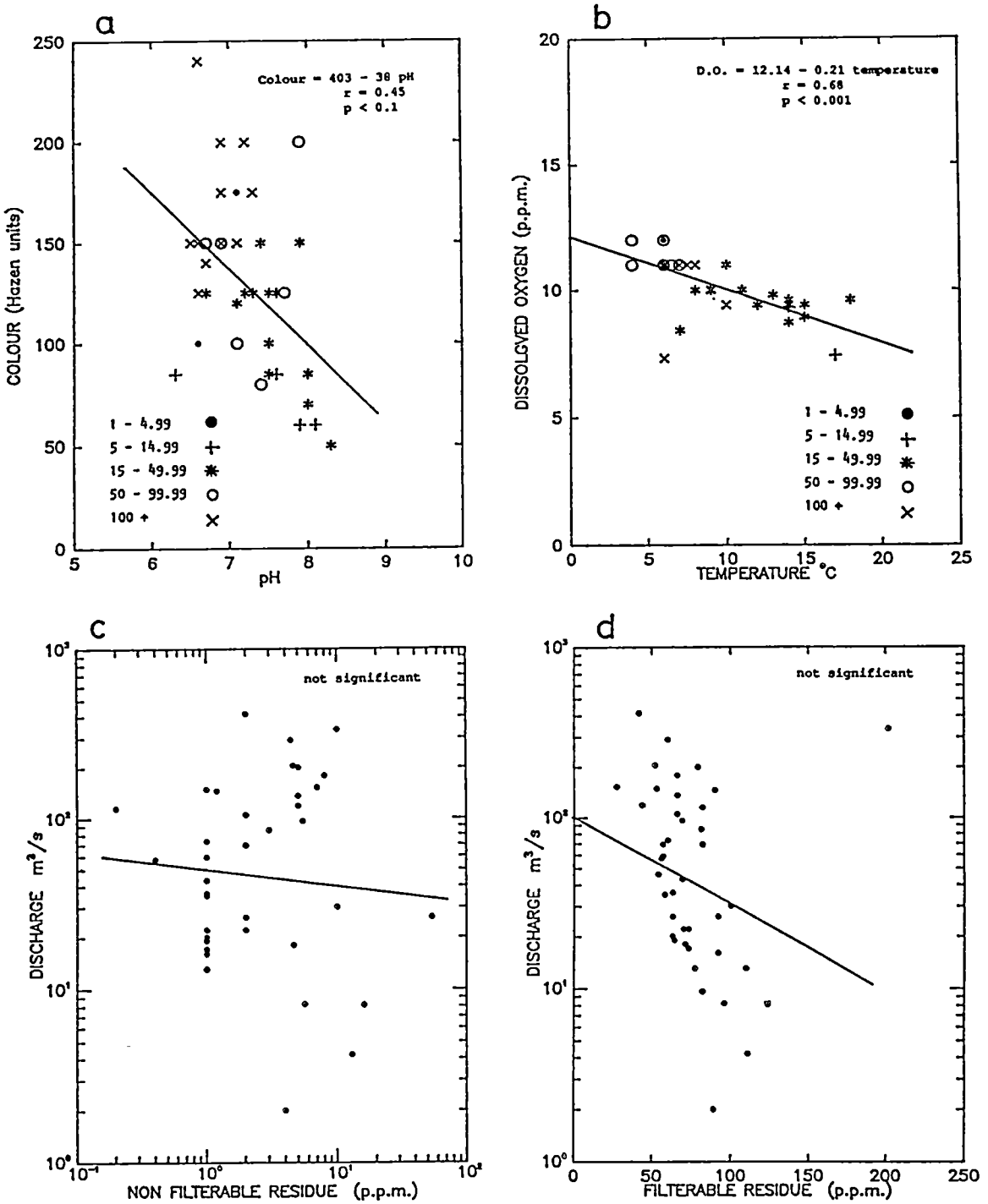


Fig. 33. Least squares relationships for the Huon River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

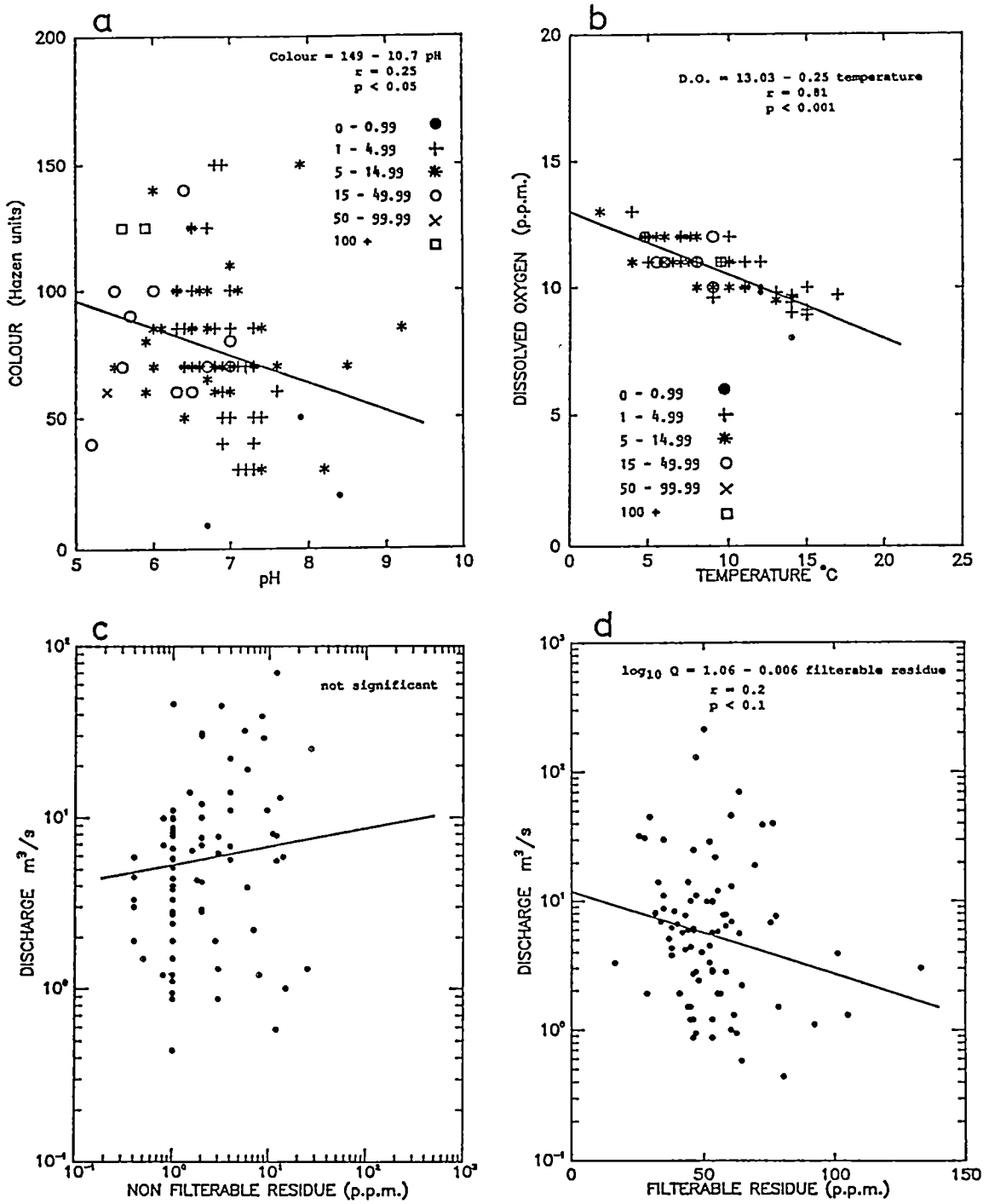


Fig. 34. Least squares relationships for the Henty River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

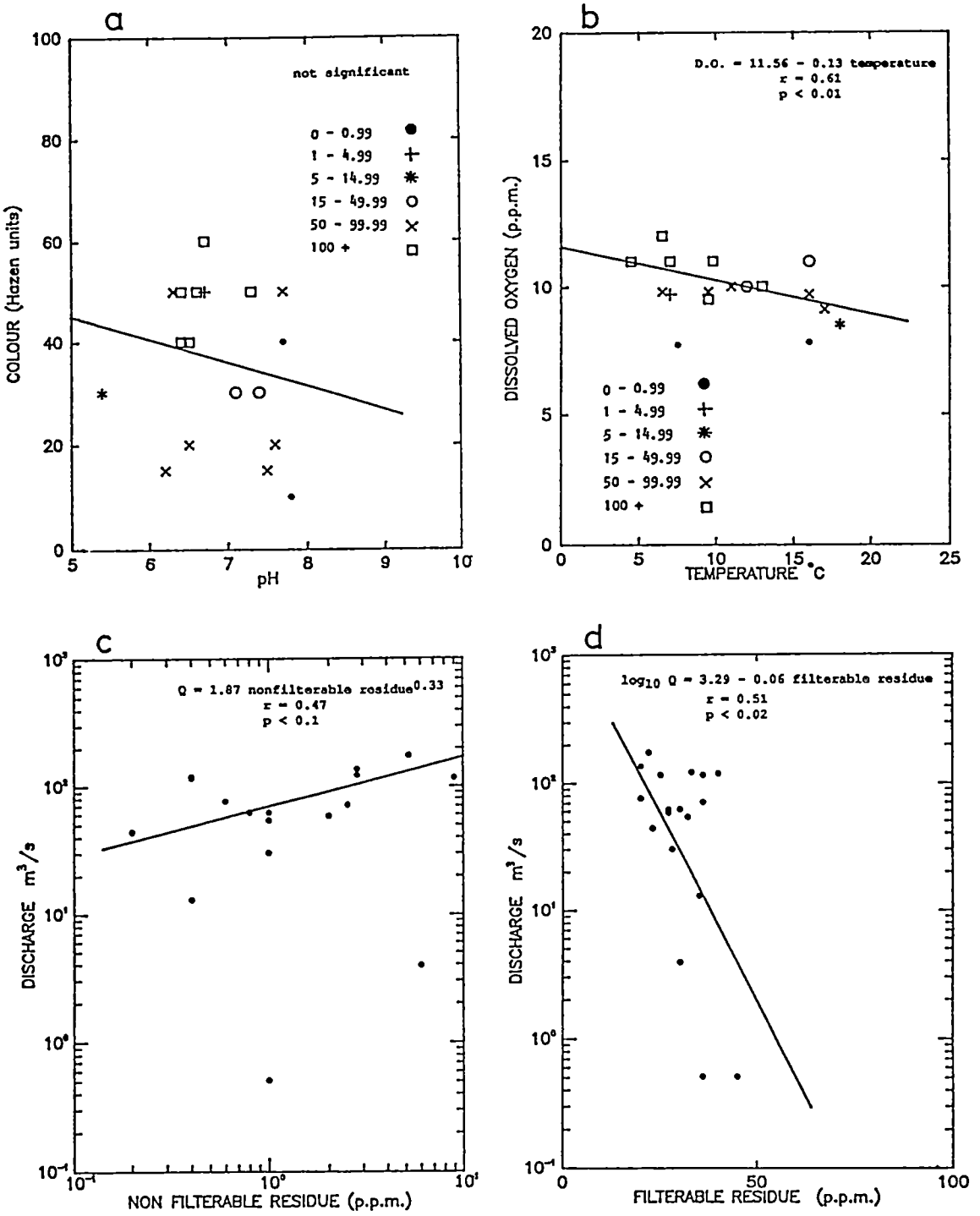


Fig. 35. Least squares relationships for the Forth River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

consistency between discharge and these variables, though it is apparent that flows greater than 100 cumecs may produce higher values for colour and dissolved oxygen. Both filterable and non filterable residue display some relationship with discharge: there is a weak trend between discharge and filterable residue ($r = 0.51$, $p < 0.02$), and a stronger trend with non filterable residue ($r = 0.47$, $p < 0.1$).

Consistent patterns between colour and pH, dissolved oxygen and temperature, and discharge appear evident for the Derwent River (fig 36). Discharges greater than 100 cumecs display colour values of > 40 hazen units and temperatures below 8 C. There are significant correlations between pH and colour ($r = 0.35$, $p < 0.1$) and between temperature and dissolved oxygen ($r = 0.53$, $p < 0.01$). Increasing discharge does not predictably decrease filterable residue ($r = 0.27$, $p > 0.1$), but there is a significant relationship between discharge and non filterable residue ($r = 0.41$, $p < 0.02$).

All the plotted variables for the South Esk River show a significant relationship (fig 37). This river belongs to hydrological group 1, together with the Great Forester, George and Mersey Rivers. There is no consistency of change in colour, pH, temperature or dissolved oxygen with discharge. Colour increases as pH decreases ($r = 0.35$, $p < 0.05$), and dissolved oxygen is negatively correlated with temperature ($r = 0.86$, $p < 0.001$). As expected, non filterable residue increases exponentially with discharge ($r = 0.43$, $p < 0.01$), while filterable residue displays an abnormal trend by increasing with discharge ($r = 0.3$, $p < 0.05$).

The Great Forester and George Rivers are located in the north-east of Tasmania where evaporation often exceeds precipitation. Relationships between colour and pH for the Great Forester River are insignificant ($r = 0.1$, $p > 0.1$), though it appears that discharges less than 1 cumec do not exceed a colour greater than 60 hazen units (fig 38).

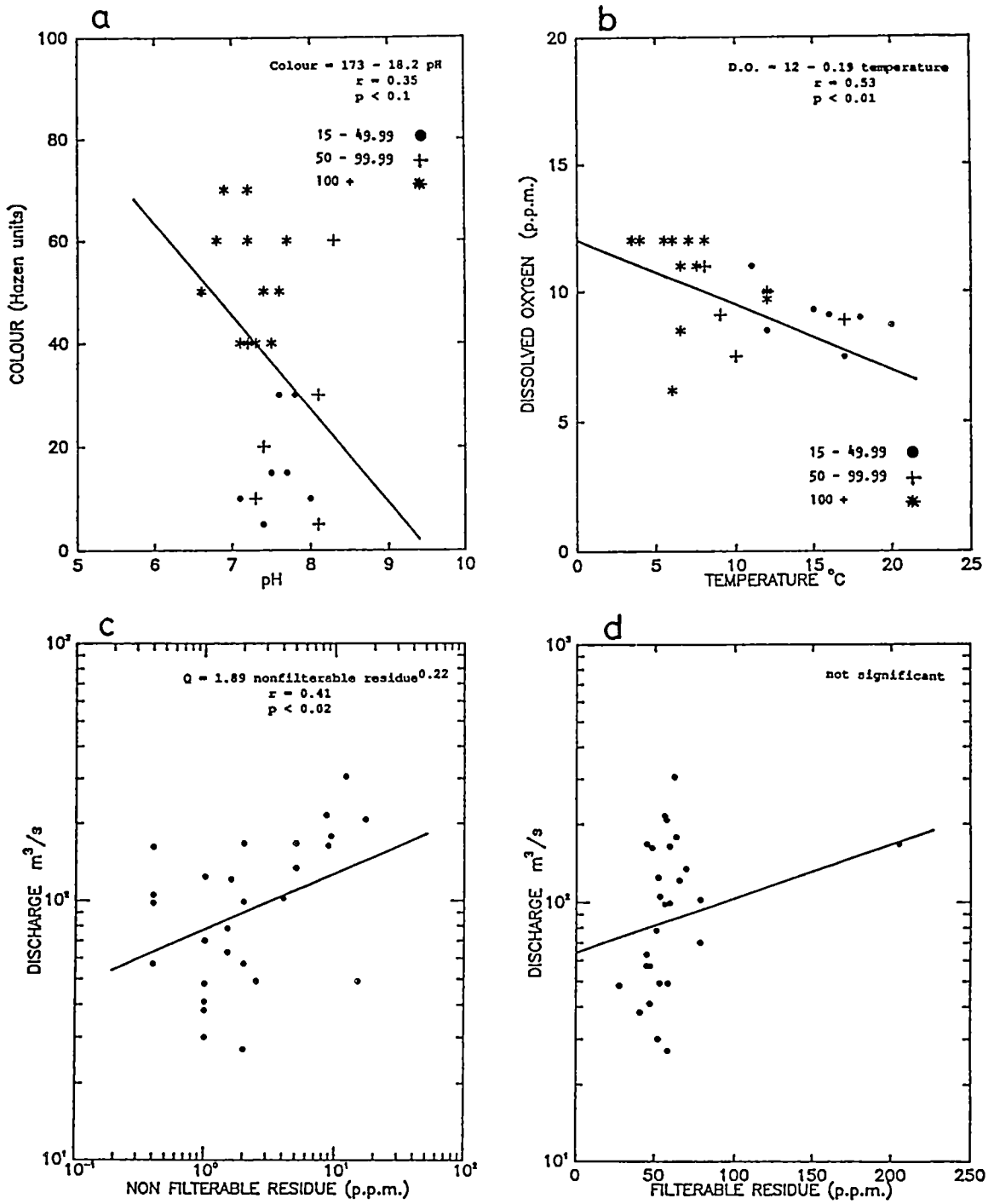


Fig. 36. Least squares relationships for the Derwent River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

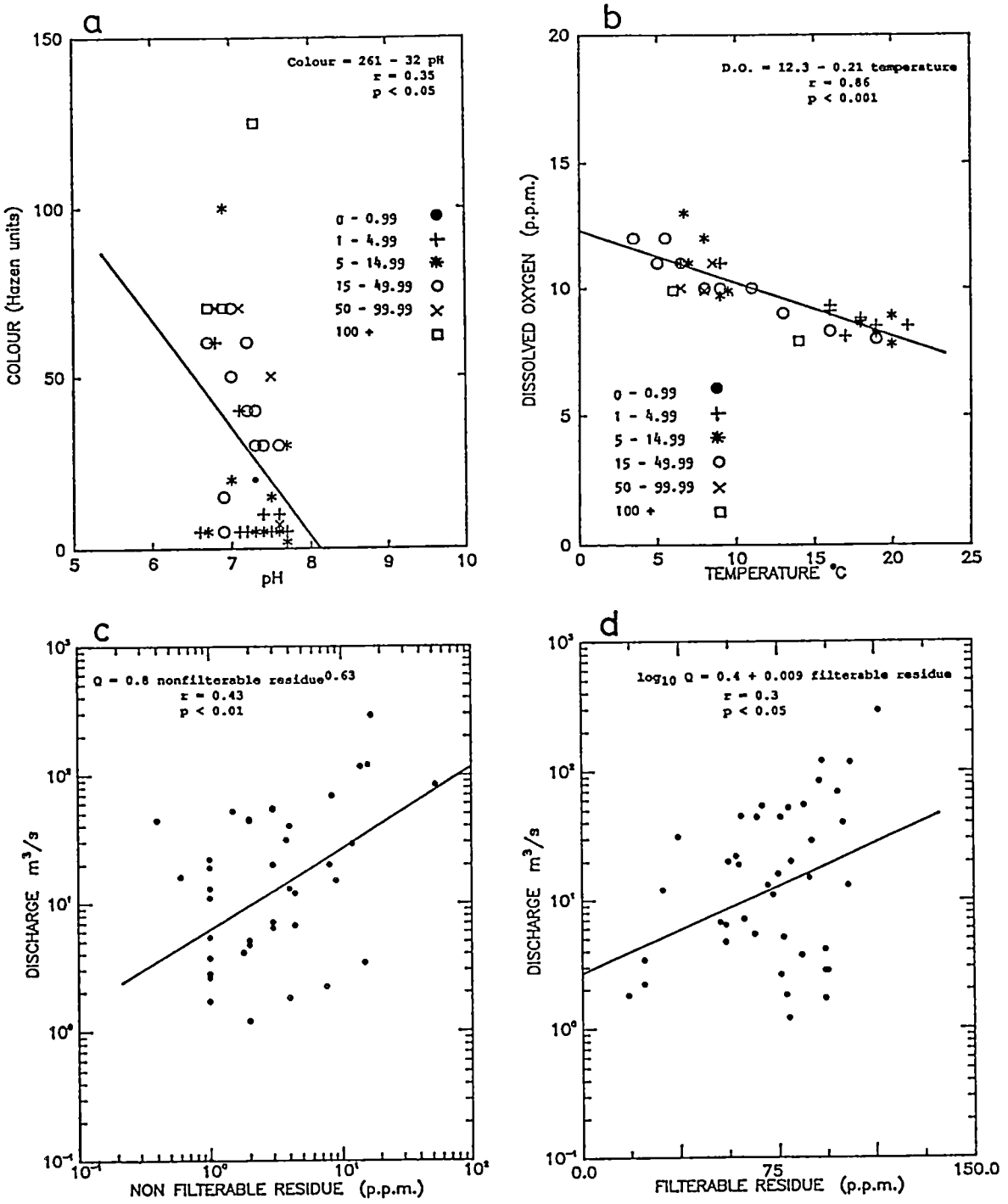


Fig. 37. Least squares relationships for the South Esk River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

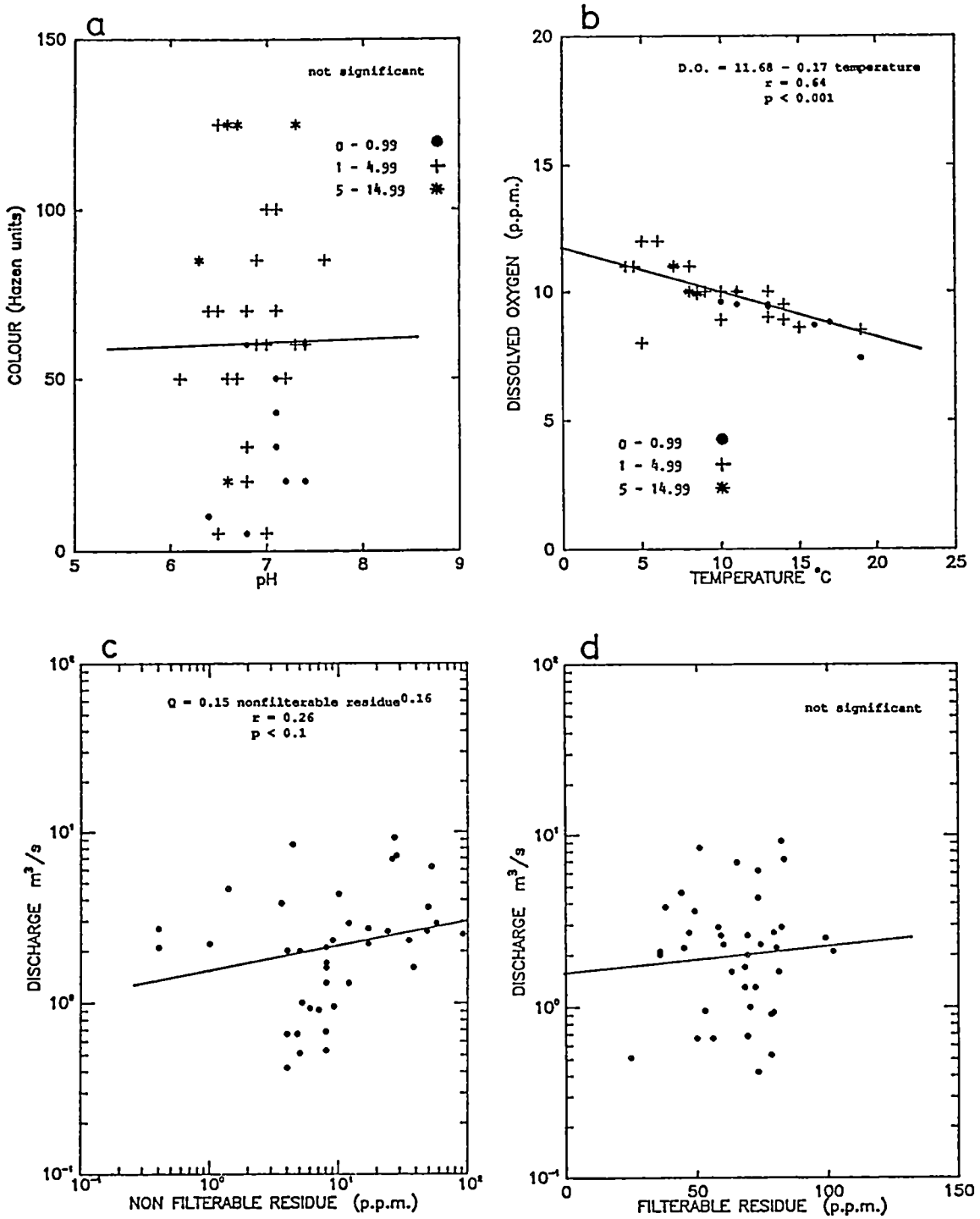


Fig. 38. Least squares relationships for the Great Forester River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

Dissolved oxygen decreases as temperature increases ($r = 0.64$, $p < 0.001$). An insignificant relationship exists between discharge and filterable residue ($r = 0.07$, $p > 0.1$), and there is a tendency for non filterable residue to increase with discharge ($r = 0.26$, $p < 0.1$).

There are significant trends between pH and colour, temperature and dissolved oxygen for the George River (fig 39). pH increases as colour decreases ($r = 0.38$, $p < 0.02$), while, predictably, dissolved oxygen decreases with increasing temperature ($r = 0.79$, $p < 0.001$). There is no consistency of change for these variables with discharge. There are positive exponential relationships between discharge, and filterable and non filterable residue ($r = 0.43$, $p < 0.01$, and $r = 0.49$, $p < 0.01$ respectively).

The Mersey River (fig 40) displays a very strong correlation between pH and colour ($r = 0.9$, $p < 0.001$). Again, the lower discharges show specificity in colour and pH, but there is no consistency with increasing flow. Dissolved oxygen decreases as temperature increases ($r = 0.67$, $p < 0.01$), and there is a tendency towards higher values of dissolved oxygen and lower temperatures for discharges greater than 15 cumecs. Non filterable residue is significantly correlated with discharge ($r = 0.61$, $p < 0.01$), while filterable residue is negatively and exponentially related ($r = 0.47$, $p < 0.05$).

Table 4 summarizes the coefficient of variation (standard deviation divided by the mean) of each variable for the 12 river basins. There are no spectacular trends for this data, however the Cv of non filterable residue is consistently high for all the rivers, indicating the unreliability of one-off sampling for this variable. The Huon River has the largest Cv and the Pet River the lowest Cv for temperature. Interestingly, the Huon, Derwent and Mersey Rivers have the highest variability for pH which probably reflects the large size of the catchments. As expected the lowest Cv of colour is for the Huon and Henty Rivers, and the highest for the Coal River.

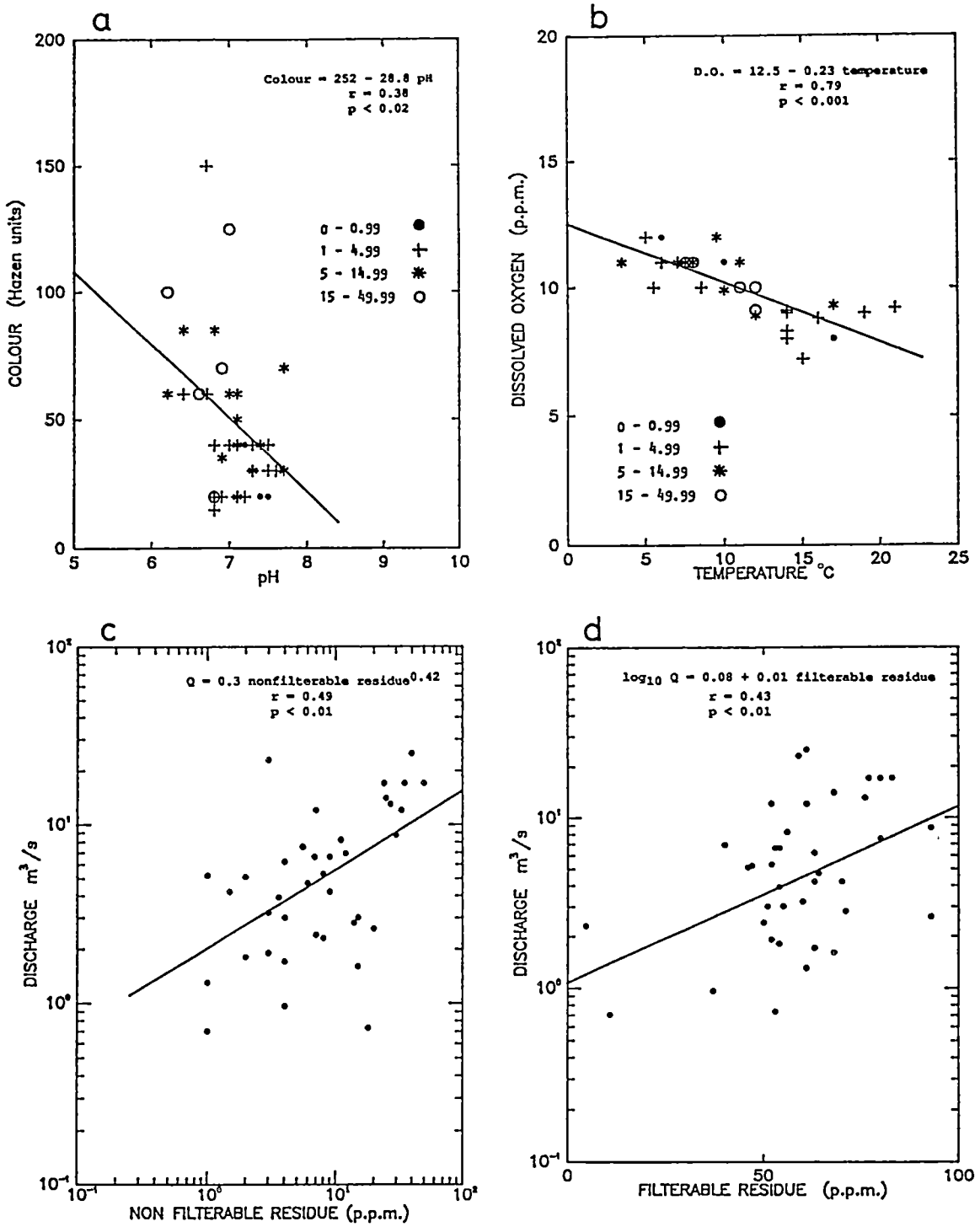


Fig. 39. Least squares relationships for the George River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

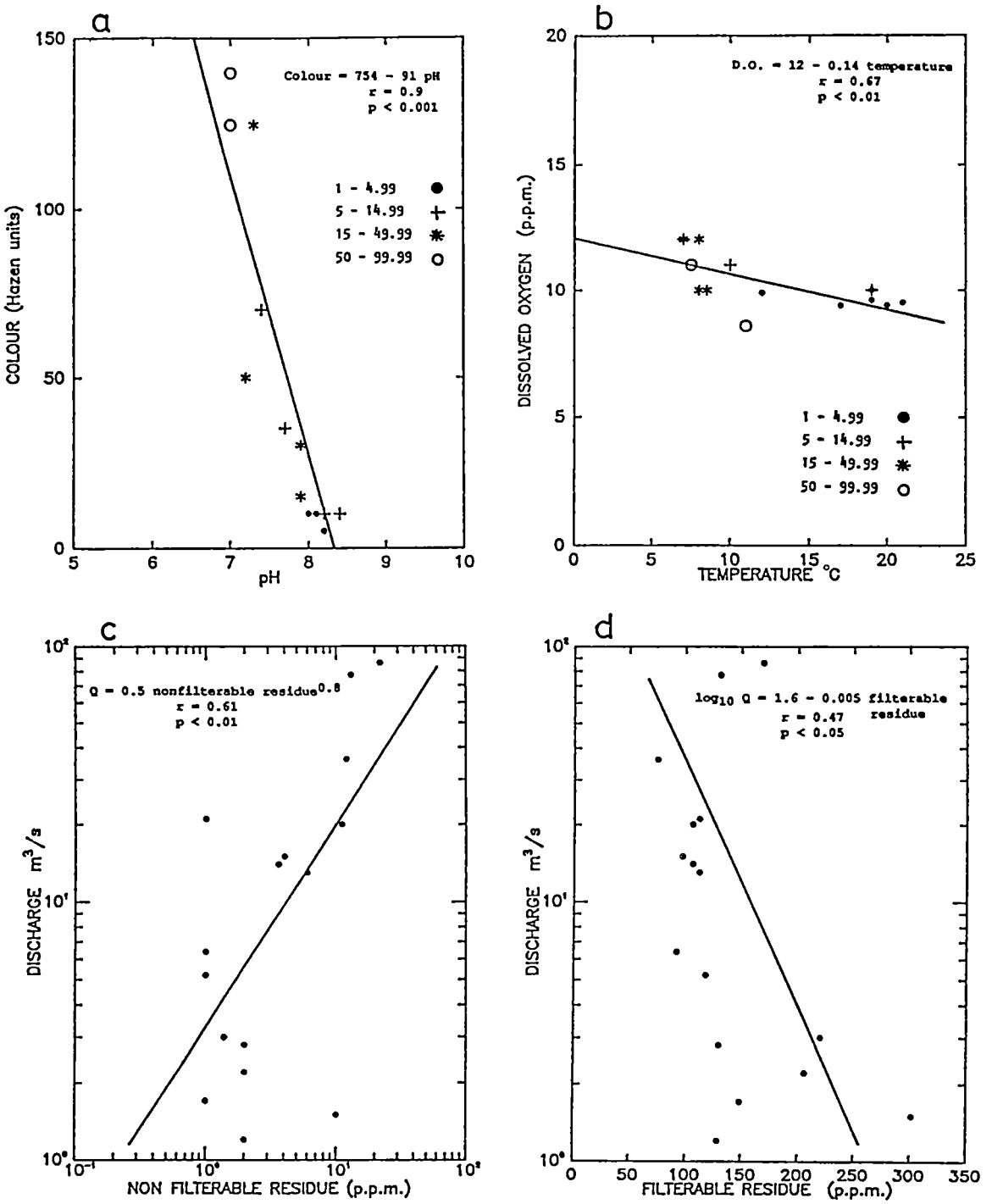


Fig. 40. Least squares relationships for the Mersey River between a) pH and colour (with discharge superimposed), b) dissolved oxygen and temperature (with discharge superimposed), c) discharge and non filterable residue, d) discharge and filterable residue

	Temperature	pH	Dissolved oxygen	Colour	Non Filterable Residue	Filterable Residue
Coal River	0.45	0.05	0.16	1.02	1.58	0.70
Derwent River	0.44	0.15	0.16	0.64	1.12	0.47
Forth River	0.40	0.07	0.22	0.59	1.87	0.5
George River	0.40	0.05	0.22	0.61	2.84	0.29
Great Forester River	0.37	0.05	0.10	0.63	1.19	0.28
Henty River	0.37	0.10	0.11	0.39	1.4	0.33
Huon River	0.49	0.11	0.27	0.33	1.79	0.37
Mersey River	0.42	0.42	0.12	0.94	1.42	0.91
North Esk River	0.47	0.05	0.17	0.79	1.4	1.19
Pet River	0.32	0.05	0.09	0.51	1.32	0.33
Prosser River	0.45	0.07	0.17	0.72	1.77	0.40
South Esk River	0.44	0.04	0.13	0.95	1.61	0.33

Table 4 Coefficients of variation of six physical and chemical attributes for the 12 rivers studied in the temporal survey.

These results demonstrate the range of values for pH, colour, dissolved oxygen, temperature, filterable and non filterable residue that may be obtained with varying discharge. There is not, however, consistency of change with discharge, either within or between river catchments, though certain predictable trends are apparent. For example, the Coal and Prosser Rivers have the highest values of filterable residue, which is to be expected for rivers experiencing low rainfall (fig 1) and consequent discharges. Least squares models for discharge and log-transformed filterable residue are significant for all rivers with the exception of the North Esk, Huon, Derwent and Great Forester. It is expected that non filterable residue be positively correlated with discharge (Walling 1977, Fenn et al.1985). However the Coal, Pet, Huon and Henty Rivers display insignificant relationships for these variables, and the log-transformed least squares models for the other catchments are very weak. The great variability which occurs in sediment response indicates that there is no simple constant relationship between discharge and suspended sediment concentration such as is suggested in the traditional use of sediment rating curves. Similar conclusions were made by Olive and Walker (1982), and Olive and Rieger (1985) for five catchments in New South Wales, indicating that sediment rating curves may be an inappropriate tool in the Australian context (Olive and Reiger 1984). Temperature and dissolved oxygen are consistently correlated for the 12 rivers, and with the exception of the Pet, Forth and Great Forester Rivers, colour increases significantly with pH. There is great variability of response of these four variables which again demonstrates the lack of constant relationship with discharge. Exceptions are displayed by the Coal, Prosser, Pet and Derwent Rivers.

2.3.3 Spatial variability of lotic water chemistry

Data and methods

Data from 66 rivers sampled by Buckney and Tyler (1976) were used in the spatial investigation, as well as data from the Tasmanian Rivers and Water Supply Commission (see R.W.S.C. 1983). 86 one-off samples were used in total, and the spatial variability of anionic and cationic composition, and pH and colour was examined. Ratios of cations and anions, and pH and colour, were mapped as well as being plotted against values of total dissolved solids. There are insufficient data on temperature and dissolved oxygen for these variables to be mapped. The temporal variability of non filterable residue in Tasmanian lotic environments is too great to be usefully used in a one-off spatial investigation (section 2.3.2). The results are compared to other regions in Australia and the world in section 2.3.4.

Results

The great variability of sodium to calcium ratios and chloride to bicarbonate ratios in figures 41b and 41c indicates that there is a spatial diversity of water chemistries for Tasmanian lotic waters. However, most of the samples in figure 41b lie within the 'boomerang' distribution of streams surveyed by Gibbs (1970). These streams are calcium enriched when compared to mainland Australian rivers (fig 41a). The distribution of points in figure 41c indicates that only 62% of the samples are within Gibbs' distribution. There is a tendency towards bicarbonate enrichment for some Tasmanian rivers, but many have chloride anionic dominance (confirmed in fig 42b). The range of total dissolved solids is considerably larger for mainland than Tasmanian rivers (18.7 - 678.3 p.p.m. for Tasmania, 7 - 10,000 p.p.m. for other Australian rivers). The ionic ratios of each sample have been mapped and graphed on figures 42a-c. It is apparent that sodium dominated lotic waters are generally in the northwest, northeast and east coast of Tasmania. Melaleuca Creek and Louisa River on the south

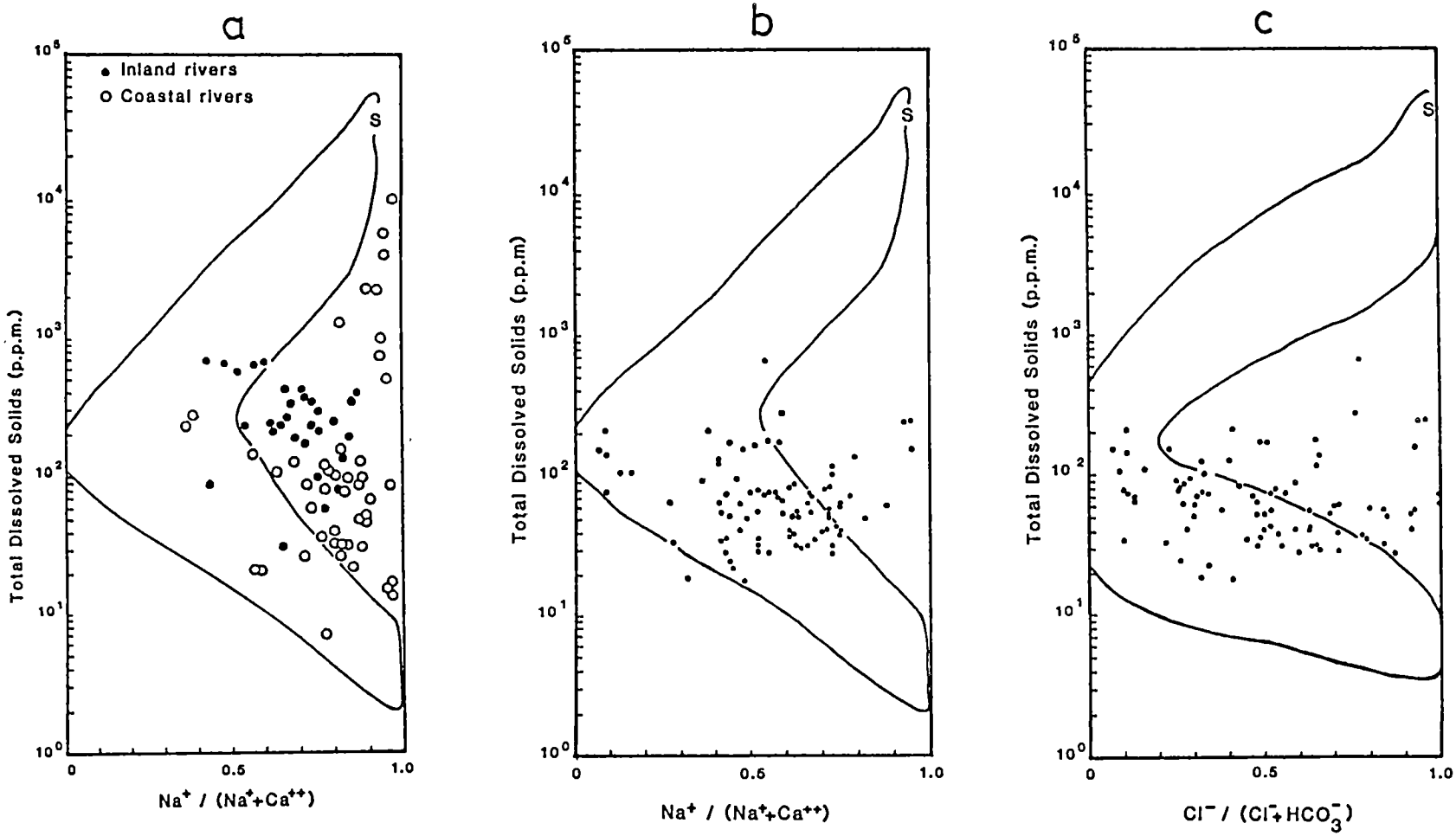


Fig. 41. The relationship between total dissolved solids (p.p.m.) and a) cationic composition of mainland Australian rivers (after Hart & M^{c}Kelvie 1986), b) cationic composition of Tasmanian rivers, c) anionic composition of Tasmanian rivers. S = seawater; ——— = envelope enclosing the original distribution of Gibbs (1970)

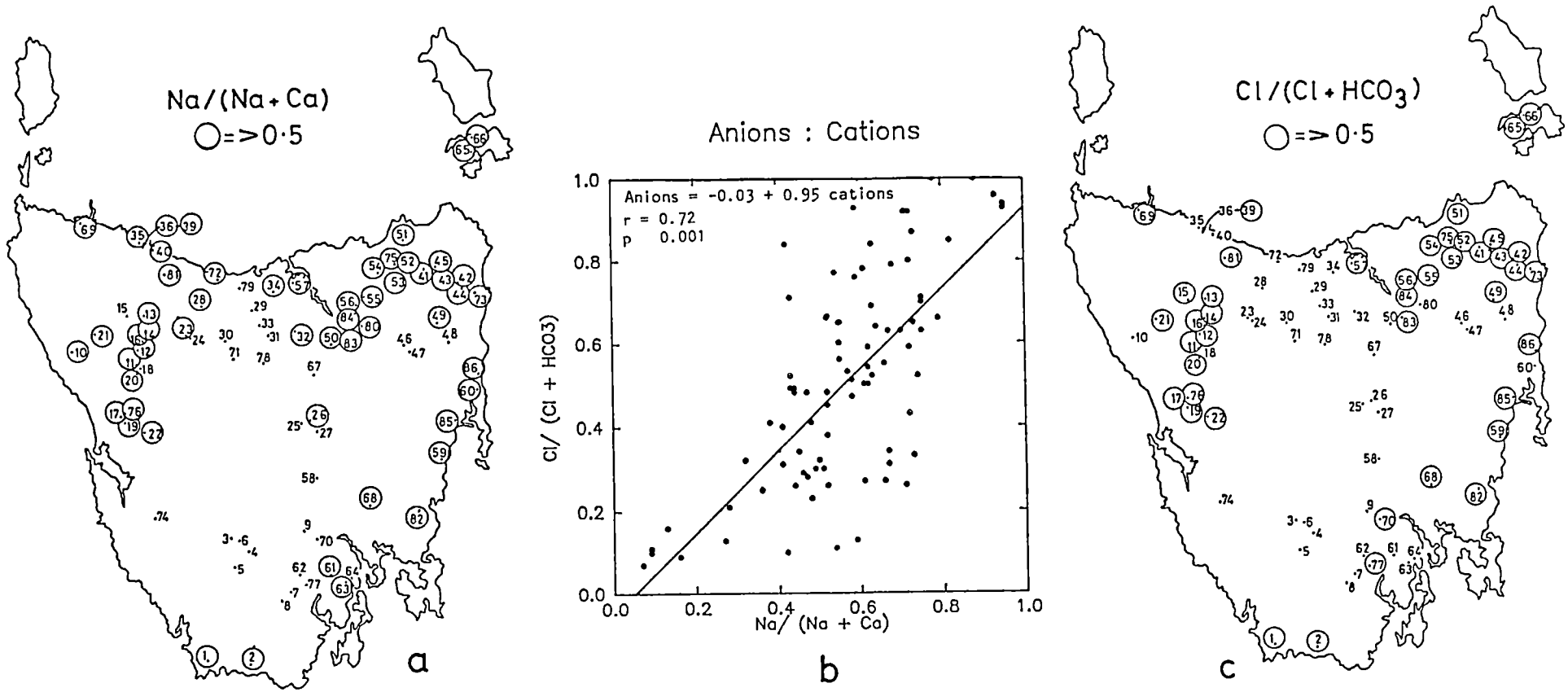
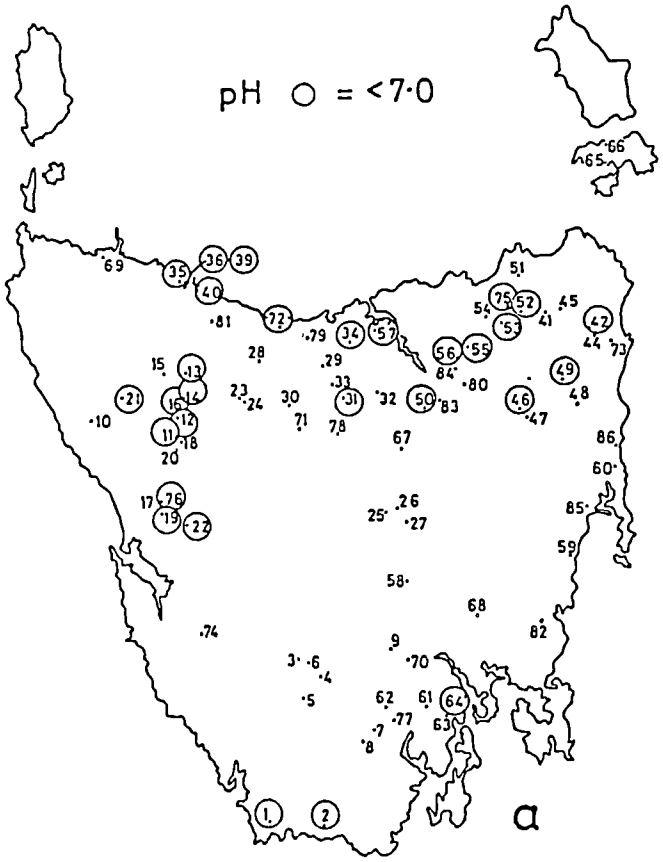
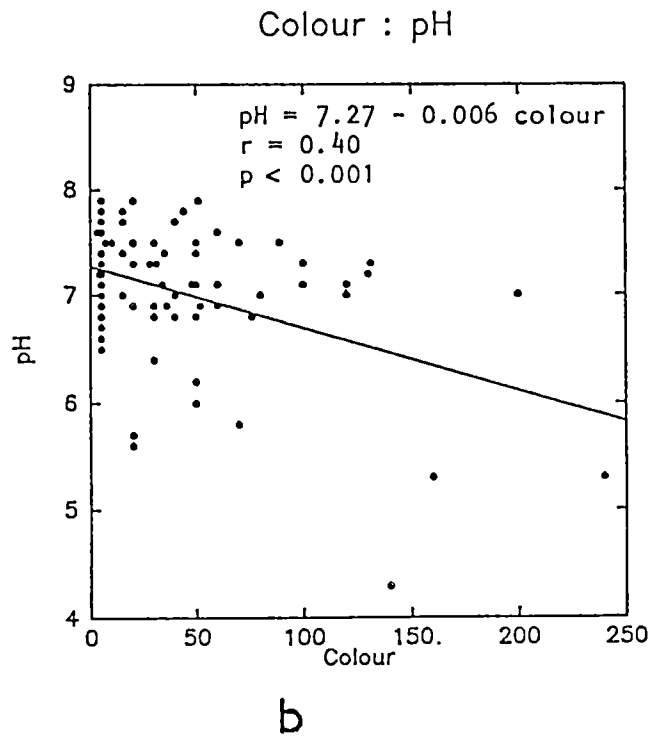


Fig. 42. a) Spatial distribution of cations for Tasmanian rivers

b) Least squares relationship between anions and cations for the 86 spatial samples

c) Spatial distribution of anions for Tasmanian rivers





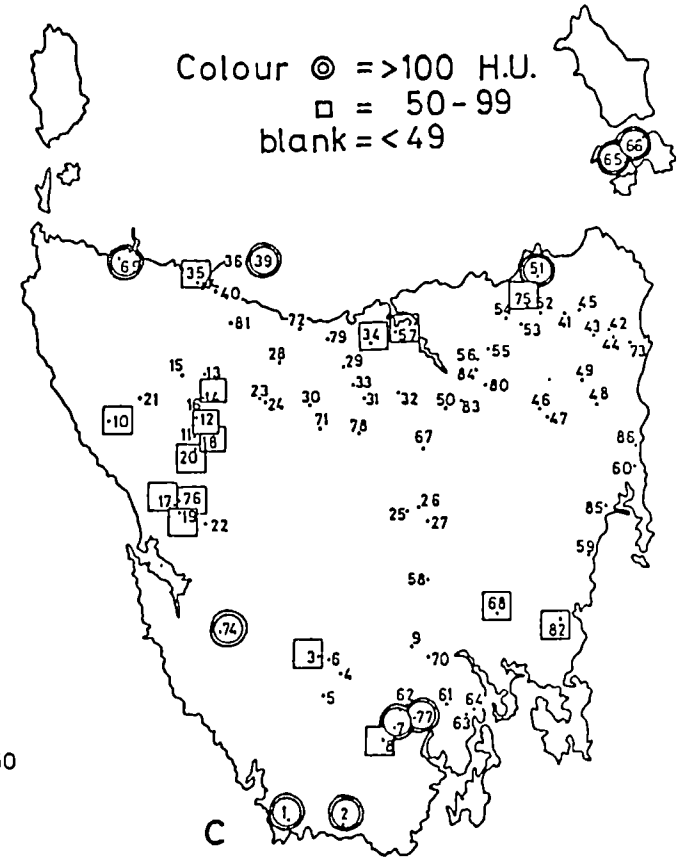


Fig. 43. a) Spatial distribution of pH for Tasmanian rivers

b) Least squares relationship between pH and colour for the 86 spatial samples

c) Spatial distribution of colour for Tasmanian rivers

coast are also sodium dominated, while rivers in the southwest and centre of Tasmania are calcium dominated. Rivers dominated by chloride anions are in the northwest, north east and east coast, and again Melaleuca Creek and Louisa River fall into this category. In the Central Plateau, southwest and central north coast rivers are bicarbonate dominated rivers. The plot of anions to cations (fig 42b) confirms these results by demonstrating the relationship between sodium and chloride ions, and calcium and bicarbonate ions ($r = 0.72$, $p < 0.001$), although some rivers e.g. the Forth, appear to be prevalent in sodium and bicarbonate ions. The results again emphasize the spatial diversity of ionic composition of Tasmanian lotic environments.

Using the Gibbs (1970) scheme, it can be seen that rivers with T.D.S. less than 100 p.p.m. range between precipitation and rock domination, with a tendency towards rock (or calcium bicarbonate) domination (fig 41). Rivers with high proportions of sodium chloride and with T.D.S. less than 100 p.p.m. are precipitation dominated and include rivers in the extreme south west, north west and some in the north east. Rivers with T.D.S. greater than 100 p.p.m., and sodium chloride dominated, are influenced by precipitation:evaporation processes e.g. rivers on Flinders Island, the south east and parts of the east and north east.

Colour and pH have been plotted in figure 43b. As expected from section 2.3.2, there is a tendency for rivers with acid waters to be more coloured than alkaline waters ($r = 0.4$, $p < 0.001$). Geographically, rivers with pH less than 7.0 occur on the west coast and the far south west of Tasmania, as well as the north west and northeast e.g. Great Forester and Ringarooma Rivers (fig 43a). The waters of these rivers drain sedgeland peats. The range of pH values in the spatial survey is 4.3 for Melaleuca Creek to 7.9 for the Coal, George, Lake and Sandfly Rivers. Rivers with colour greater than 50 hazen units (fig 43c) are confined to the west,

south west and selected rivers in the north of the state. Surprisingly, the Prosser and Coal Rivers fall into this category. Inconsistent and unexpected results for the spatial distribution of pH and colour, confirm the findings of section 2.3.2, which highlighted the temporal variability of these variables. Random, occasional samples can be misleading, especially for rivers experiencing large ranges and standard deviations of results e.g. the Prosser and Coal Rivers have the largest standard deviations for colour (table 3).

Fig 44 indicates that values of total dissolved solids larger than 100 p.p.m. are to be found in the drier south east of the state, and the south west. Other examples with high T.D.S tend to be in the north, for rivers draining the Western Tiers, and for rivers whose sample site was in a coastal situation. Levels of T.D.S may increase due to runoff from agricultural areas.

2.3.4 Comparisons with other regions in Australia and the world

An excellent review of the aquatic chemistry of Australian rivers and lakes is provided by Hart and McKelvie (1986). This article, together with studies for particular regions of Australia (e.g. Williams and Buckney 1976, Muir and Johnson 1979, Buckney 1980, Buckney and Tyler 1973) and the world (e.g. Gibbs 1970, Lindskov and Kimball 1984, Maderak 1966, Edwards 1973, Hem 1985), will provide the basis for the following comparison.

According to Gibbs (1970) the chemistry of lotic environments is largely determined by atmospheric supply, evaporation-crystallization processes and terrestrial contributions. Additionally there is the biological contribution of dissolved atmospheric gases (Hutchinson 1957, Hynes 1970). In Tasmanian rivers, the dominance of factors determining water chemistry will alter with seasonal and annual changes of rainfall and discharge. Atmospheric

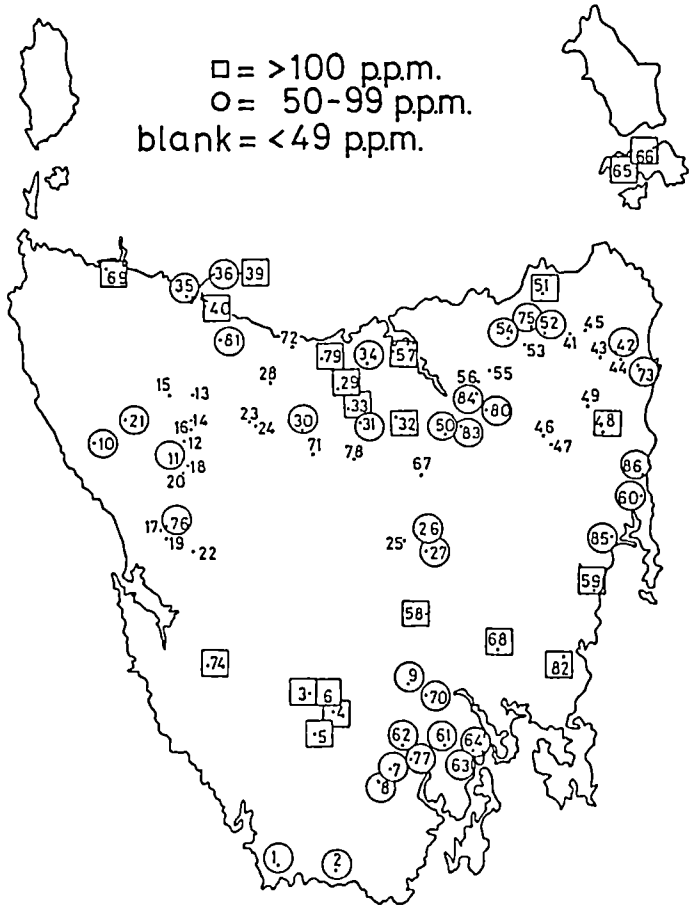


Fig. 44. Spatial distribution of total dissolved solids for Tasmanian rivers

and terrestrial contributions of ions may be dominant when rainfall is high, and evaporation-crystallization processes may be dominant in controlling water chemistry during drier periods. Additionally, in areas with high Cv of discharge catchment soils may be in contact with water for a considerable time. The first discharges after a dry period may thus be chemically unusual (Buckney 1980). It is apparent that each river basin will react differently to these various mechanisms, and will reflect different geologies, hydrologies and precipitation regimes.

a)Stoichiometry

Edwards (1973) examined the temporal relationship between dissolved constituents and discharge in three Norfolk rivers, and demonstrated some inconsistency of dilution patterns of dissolved load with discharge (namely chloride, bicarbonate, calcium and potassium). The inconsistencies are attributed to the small fluctuations of discharge (discharges range over two orders of magnitude), and the highly variable nature of the minerals in the catchment. The results of Edwards (1973) contrast with those of Hem (1985) and Maderak (1966) who worked along rivers in the western United States experiencing wide seasonal fluctuations. Hem (1985) evaluated data from the San Francisco River, Arizona, and derived a hyperbolic relationship between discharge and concentration (page 181). Predictable changes from sodium dominance to calcium and magnesium dominance during high flows were recorded for the Heart River, North Dakota (Maderak 1966).

The Prosser and Coal Rivers, which belong to hydrological group 2, display similar predictable tendencies, away from seawater stoichiometry. Hydrological group 2 experiences high coefficients of variation of annual and seasonal flows and low mean annual runoff. At low flows, the streamflow will consist predominantly of groundwater, and with increasing rainfall, increasing amounts of interflow and surface runoff enter the stream with a corresponding increase in earth bicarbonates. The Great Forester River

also exhibits predictable changes in stoichiometry with discharge, towards seawater stoichiometry with increasing discharge. In large catchments, with waters from many tributaries, or in catchments of variable geology and landuse, only a relatively small proportion of the variance in ionic concentrations may be explained by discharge. This appears to be the case for the nine other rivers considered in the temporal survey, and particularly for the South Esk which displayed no trends with discharge for ionic composition.

There are few temporal studies relating discharge to changes in stoichiometry in Australia. There was no significant correlation between discharge and anions for the South Esk River (Norris et al. 1980), but relationships existed for the Derwent and Gordon Rivers (Buckney 1977, King and Tyler 1982). These studies are consistent with the above results. Muir and Johnson (1979) found groundwater inputs to be of importance in the Cudgegong River, New South Wales. Ionic dominance and salinity could be related to the weathering of specific geological strata in the catchment, and to the rivers' discharge. Under low flow conditions the middle section of the river displayed calcium dominance, tending towards sodium dominance during higher flows.

It is apparent that stoichiometric changes in river waters are extremely site specific. It is not possible to regionalize changes in anions and cations over time, though it is possible to predict certain changes in the drier parts of Tasmania with increasing discharge. In the northern and western regions, changes in stoichiometry are very dependent on local geology and seasonality of hydrological events. These results are in agreement with other temporal studies undertaken in Australia, and those in the northern hemisphere.

Spatially, Tasmania affords contrasting and contiguous ionic environments. The drier regions of the State exhibit river stoichiometries comparable to the drier parts of mainland

Australia, though levels of total dissolved solids do not exceed 800 p.p.m.. Rivers in the southwest and centre of Tasmania are calcium dominated, thus exhibiting a cationic dominance that is not predominant for mainland Australian Rivers (see Williams and Wan 1972, Williams and Buckney 1976, Buckney 1980).

b) Other parameters

Temperatures for the 12 rivers did not show great temporal variation (tables 2 and 3) and appear to exhibit the same annual and geographic variation as those in other zones. Welcomme (1986) describes annual temperature variations of 20 to 30 ^{o}C for the Niger River, and Crawford (1985) measured variation of 1 to 33 ^{o}C for rivers in North Carolina (with Cv of average 0.47). Williams (1981) quotes ranges of 11 to 29 ^{o}C in semi-arid lotic environments in Australia, 0 to 20 ^{o}C for high altitude rivers in the south east and 7 to 27 ^{o}C for low altitude south eastern rivers. The range of temperatures in table 3 is comparable with rivers in south eastern Australia (Lake et al. 1985a, Table 3), however it is to be remembered that of the 12 sample sites in this study, none are situated at high altitude. Annually, stream temperatures follow a harmonic function (Steele 1978) and are coolest in high altitude, high latitude locations.

Lindskov and Kimball (1984) recorded little variation of pH for rivers in the Uinta Basin, Colorado, and no significant correlation of pH with flow, or pH with the concentration of any of the major constituents. Similar lack of variation was documented by Muir and Johnson (1979) for the Cudgegong River in New South Wales. pH in this study displayed small ranges and low coefficients of variation (table 3 and 4). Small temporal variations in pH may be explained by the fact that if pH is not extreme, it tends to be regulated by the CO_2/ HCO_3^-/ CO_3^{2-} buffer system (Hart 1974). For instance, if the water has a high total alkalinity, an acid addition may be neutralised without a change in pH occurring. The spatial variation of pH in Tasmania is considerable, ranging from

acidic rivers in the southwest and northeast (lowest pH is 4.2) to rivers with pH of up to 7.9 in the east and south east. In the south west of Tasmania , and parts of the north east and west coast, there are large areas of peat soil derived from Gymnoschoenus sphaerocephalus. Waters draining these peats are more acidic than other parts of the State. It is also of interest to note that acid rain in northern Europe (pH < 5.6) has resulted in values of stream pH comparable with the south west of Tasmania (Neal et al. 1986). Hem (1985) states pH values of 6 to 8.5 for groundwater in the United States, and waters with low pH are not uncommon in thermal springs. River waters not influenced by pollution in the U.S. generally have a range of 6.5 to 8.5 (Hem 1985, Engberg 1983). Shiel et al. (1982) during a study of plankton in the lower River Murray measured a range of pH of 7.0 to 8.8. There were rapid changes during peak discharges and during a bloom of cyanobacteria .

With the exception of the study by Shiel et al. (1982), no Australian literature was found describing spatial or temporal variation of dissolved oxygen in lotic environments. Hart (1974) states that there may be considerable diurnal and seasonal fluctuations in dissolved oxygen due to changes in water temperature and photosynthetic rates, but does not give any examples. There is some correlation with discharge in this study, but levels of dissolved oxygen mainly reflect temperature (or seasonal) variation. Lindskov and Kimball (1984) found variations of 3.8 to 11.3 mg/l and 5.9 to 12.2 mg/l for Evacuation and Willow Creeks in the Uinta Basin over a three year period. Crawford (1985) recorded variation of 5.9 to 17.5 mg/l for Deep River in North Carolina. Shiel et al. (1982) rarely recorded levels below 90% saturation for the Murray River, with the lowest levels during floods. They recorded a range (and mean) of 6.4 to 12.0 (9.4) mg/l. Data measuring variability of colour for Australian and world rivers are equally elusive, and no comparative data were found.

The lack of response of non filterable residue with discharge in this study and other Australian rivers has already been discussed (section 2.3.2), and contrasts to the relations obtained for filterable residue. Shiel et al. (1982) found that total dissolved solids ranged from 100-660 mg/1 for the lower Murray River, with the highest levels recorded in summer. This range compares with the Tasmanian data, although the Coal River exhibits considerably higher values of filterable residue. Williams (1981) states a range of salinity of 20 to 6000 p.p.m. for Australian running waters, and adds that most have salinities of less than 400 p.p.m.. Ranges of conductance of 80 to 940 and 42 to 460 μS cm^{-1} were recorded for the Cudgegong and Bogan Rivers (N.S.W.) respectively (Muir and Johnson 1978, 1979), and Reinson (1976) measured levels of conductance from 90 to 114 μScm^{-1} (headwaters) and 231 to 359 μS cm^{-1} (Jones Creek) in a study of the hydrochemistry of the Genoa River basin (N.S.W.-Victoria). All measurements of conductance varied significantly with season and discharge. North American studies have displayed similar correlations between dissolved solids and discharge (Lewis and Grant 1979, Lindskov and Kimball 1984, Hem 1985).

2.4 Levels of variability

The four-group hydrological classification has highlighted the spatial diversity of river hydrologies to be found across Tasmania, and potential levels of disturbance. The driest south-east group exhibits regimes similar to the drier mainland areas, while the wettest region has no analogue in mainland Australia. Groups 1 and 4 have more temperate regimes. Comparisons between figures 1 and 3 demonstrate how the classification coincides, broadly, with the rainfall distribution. Differences in hydrology that cannot be accounted for by precipitation may be explained by topography, geology and soils.

Contiguous hydrological regions which exhibit distinctive and diverse river hydrologies provide an ideal framework within which to compare distributions of lotic organisms. Rivers in the south-east of Tasmania (group 2) have the lowest mean annual runoffs, the highest coefficients of variation of annual flows and the highest positive skewness. There is a tendency for group 2 rivers to have low values of persistence. Conversely, group 3 rivers (the south and west) have the highest mean annual runoffs, together with the lowest coefficients of variation of annual flows. Rivers in the north-west and north-east (group 4) have the most normal distribution of annual flows, and there is a trend towards larger values of the serial correlation coefficient r_1 for both groups 3 and 4. Group 1 rivers (north-central and north-east) and group 4 rivers have annual flow regimes similar to temperate regions. Annual flows for group 4 rivers most closely resemble rivers in the south and west (group 3) while group 1 regimes most closely resemble those of group 2 (in the south-east). It would appear that annual levels of disturbance are proportionally higher along south-eastern rivers than elsewhere in Tasmania.

Seasonality of hydrologic events can play an important role in the life histories of stream biota (see Bunn 1986, Lake et al. 1985a, Campbell 1986a). Variability for monthly flows is highest for groups 1 and 2, and lowest in group 3. This pattern is repeated for peak and low monthly events. Variability of annual flows and monthly flows is exponentially related. Rivers with aseasonal peaks or lows may be inhabited by organisms with adapted life histories, or by organisms physiologically adapted to stochastic hydrological events. South-eastern rivers with unpredictable hydrological peaks and lows may favour individualistic communities with r-adapted species.

Traditionally, peak annual flow events are considered to be the most influential cause of disturbance in streams. Group 2 rivers have higher specific mean peak annual flows than groups 1, 3 and 4. Index of variability of peak annual flows is highest in group 2 and lowest in group 3. This consistent pattern also applies to skewness of peak events, where group 3 has the most normally distributed peak annual flows. Mean peak annual flows are related to catchment area, and there is no group specificity. Within each group, specific peak flows increase with mean annual runoff, though the relationship is not a strong or consistent one.

The importance of low flow events as a disturbance factor along streams has also been stressed (Fisher et al. 1982), and especially for Australia (Boulton and Suter 1986, McMahon 1973). When considering low annual flow regimes, group 2 rivers have the lowest specific mean low annual flows and group 3 rivers have the highest. Group 2 has the most variable low flow, while group 4 rivers have the lowest variability.

Likewise the survey of Tasmanian lotic chemistry has emphasized the spatial diversity of chemical environments across the State. Contrasting and contiguous environments provide an adequate framework within which to compare the distribution of lotic organisms. In summary the spatial

survey demonstrated that:

a) Rivers in the north, east and northwest have seawater stoichiometries, along with near-coastal rivers in the south west. These rivers have anions and cations dominated by chloride and sodium respectively.

b) Rivers with anions and cations dominated by bicarbonate and calcium are found in the south west and north central regions of the State where rock-dominated mechanisms influence the water chemistry.

c) Dilute lotic waters (< 50 p.p.m.) are found in rivers on the central plateau or rivers which drain mountainous terrain with little soil retention e.g. Ben Lomond Massif. Rivers with filterable residue greater than 100 p.p.m. are found in the drier parts of the State where evaporation exceeds precipitation, or in areas dominated by precipitation rich in sea salts.

d) Lotic waters with pH less than 7.0 are to be found in the north west, north east and south coast. This distribution coincides broadly with rivers experiencing colour greater than 50 hazen units. Some north eastern rivers with acidic waters have colour values less than 49 hazen units.

Within this spatial pattern there is temporal variability. Temporal variability of the chemistry of rivers can be crucial to some stream organisms (see Hart 1974). The results of the temporal survey demonstrate that:

a) Temporal changes are extremely river-specific and are influenced by the geology of the catchment. There appear to be no geographically distinct regions which exhibit the same range in temporal variability.

b) Variations in stoichiometry show inconsistencies with discharge for most areas in Tasmania, with the exception of the Coal, Prosser and Great Forester Rivers (where evaporation exceeds precipitation). Despite variation in stoichiometry it is possible to define distinctive chemical groupings for lotic waters in Tasmania. These have been described in the spatial survey.

c) The coefficient of variation of pH, dissolved oxygen and temperature is less than 0.49, demonstrating small temporal variability of these parameters.

d) The ranges of coefficient of variation of filterable residue and colour are 0.33 to 1.02 for colour and 0.28 to 1.19 for filterable residue, demonstrating high variability for some rivers.

e) The coefficient of variation of non filterable residue is above 1.12 for all rivers indicating high temporal variability for this variable. Non filterable residue tends towards positive correlations with discharge, though this is not consistent.

Chapter 3

Vegetation dynamics following disturbance

3.1 Introduction

Stanford and Ward (1983), in their paper on insect species diversity, suggested that predictable environmental variability (particularly in temperature) may determine the number of insects in a section of stream, while biotic interactions (e.g. predation) will promote evenness in species numbers. They further speculated that intermediate levels of disturbance produce optimal environmental variability, by precluding competition and hence allowing the coexistence of few dominant species and a greater total number of species (see also Connell 1978, Huston 1979). These ideas have been reviewed in section 1.3 of this thesis, together with opinions on the appropriateness of individualistic and organismic concepts, and plant succession, for lotic plant communities.

Various types of disturbance, together with ensuing vegetation dynamics have been considered for different vegetation communities. For example Garwood et al. (1979) examined the effects of landslides and other earth movements and their effects on tropical rainforest regeneration, and Chabrek and Palmisano (1973) investigated the effects of Hurricane Camille on the marshes of the Mississippi River Delta. There have been numerous investigations into vegetation dynamics following fire disturbance (e.g. DeBenedetti and Parsons 1984, Gimingham et al. 1981, Dickinson and Kirkpatrick 1987 in press). There are no studies investigating disturbance by flooding/droughting and subsequent vegetation dynamics for lotic plant communities.

This chapter uses permanent quadrats (sensu Austin 1981) to investigate vegetation dynamics in relation to a range of

hydrologic events, and associated changes in water chemistry, for two rivers in the central east coast of Tasmania. An investigation of aquatic vegetation changes in relation to floods and droughts can give some idea of (possible) hydrological disturbances of lotic plant communities. In this case the effects of disturbance are measured in terms of displacement of community structure in 14 permanent quadrats, and changes in species cover, richness, diversity, turnover and evenness are monitored over time. The permanent plots will also elucidate whether lotic plant communities can be regarded as individualistic plant assemblages that owe their change in community structure to the frequency and magnitude of disturbances. Thus the hypotheses are tested that the direction of change of plots over time is random, and there is no similarity of change between plots over time.

3.2 The study area

3.2.1 Site selection

The Apsley and Swan Rivers (see fig 45) were chosen as sites for the establishment of permanent plots on several grounds:

a) The rivers have high specific peak flows (see Appendix 1) of 1.179 and 1.504 $\bar{Q}$ max ($m^3/s/km^2$) for the Swan and Apsley Rivers respectively.

b) The Apsley and Swan Rivers experience low specific low flows (see Appendix 1) of 0.6903 and 0.6094 $\bar{Q}$ low ($m^3/s/km^2$) x 10^{-4} respectively.

c) Both rivers are classified under hydrologic group 2, which experiences low mean annual runoff, high coefficients of annual flow and high positive skewness. Variability of monthly, peak and low monthly flows is high for group 2 rivers.

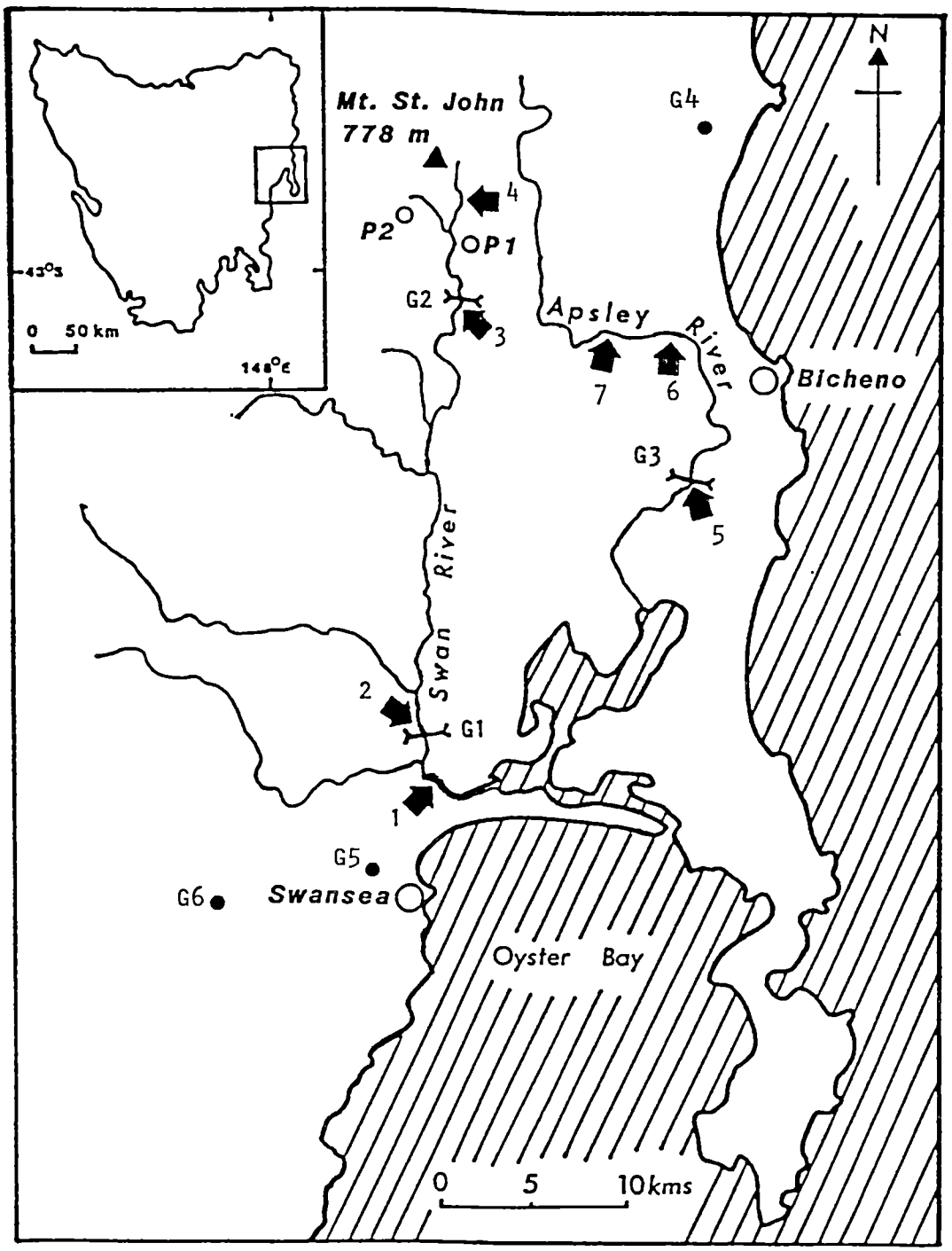


Fig. 45. Location of the three stream gauging stations: G1 = stream gauge on the Swan River at the Grange; G2 = stream gauge on the Swan River at Hardings Falls; G3 = stream gauge on the Apsley River upstream (u/s) of the Coles Bay Road. P1 = pluviograph 1; P2 = pluviograph 2. The location of the water sampling sites is indicated by an arrow: Swan River at 1 = Jetty Road, 2 = Grange, 3 = Hardings Falls, 4 = Upper Swan; Apsley River at 5 = u/s of the Coles Bay Road, 6 = Causeway, 7 = Rosedale. The three additional gauges used in the regional flood analysis are indicated by a dot • : G4 = Douglas River; G5 = Meredith River u/s of the highway; G6 = Meredith River at Goatrock Creek

d) Rivers experiencing variable hydrological regimes (such as group 2 rivers) appear to exhibit predictable changes in water chemistry (see section 2.3.2).

e) The rivers support suitably diverse communities of aquatic angiosperms along their lengths, and in the case of the Swan River, diverse aquatic angiosperms grow in the brackish component of the river.

f) The rivers are readily accessible from Hobart, and have the added practicality (for sampling purposes) of being easily wadeable.

3.2.2 Climate, geology and landuse

The central east coast of Tasmania experiences a subhumid climate and precipitation tends to fall in late spring early summer (Gentilli 1972). Bicheno and Swansea are the nearest temperature recording stations for the Swan and Apsley Rivers (fig 45). Mean daily maximum temperatures are 21.7°C and 22.0°C for the warmest month, and 6.1°C and 3.6°C for the coldest month for Bicheno and Swansea respectively (Bureau of Meteorology 1975).

A temperature value for Mt. St. John, in the headwaters of the Swan and Apsley Rivers (see fig 45), was calculated by applying empirically derived environmental lapse rates to the Bicheno data: January mean daily maximum temperature = -0.87°C per 100 metres; July mean daily minimum temperature = -0.42°C per 100 metres (Nunez pers. comm., Nunez and Colhoun 1986). January mean daily maximum and July mean daily minimum temperatures for Mt. St. John are calculated as 14.61°C and 3.16°C respectively.

Mean annual rainfall for Bicheno is 684mm, and for Swansea 619mm (Bureau of Meteorolgy 1975). Rainfall measured with a pluviograph (P1 on fig 45), situated at an altitude of 400m in the vicinity Mt. St. John, from July 1984 to August 1986

(see Appendix 2), indicated a significantly higher mean annual rainfall of 1512 mm, compared with 776mm and 878mm for Swansea and Bicheno during the same period. A second pluviograph (P2 on fig 45) at an altitude of 500 metres, demonstrated a similar mean annual rainfall of 1342 mm over the same period.

The Swan and Apsley Rivers rise in the east coast hills at altitudes of approximately 700 metres. The Apsley River drains a catchment of 155 km^2 (at stream gauge G3) and flows 50 km from its source to the Apsley Marshes, at the north western end of Moulting Lagoon. The river is essentially a first order river (using magnitude ordering after Shreve 1966), though there are several intermittent tributaries. The Swan River has a catchment area of 448 km^2 (at stream gauge G1) and flows 45 km from its source to King Bay at the southern end of Moulting Lagoon. The Cygnet, Wye and West Swan Rivers drain into the Swan River, which may be categorised as a fourth order river (after Shreve 1966). The Swan River is tidally influenced for six kilometres upstream from the mouth.

The upper and middle reaches of the rivers flow over a Jurassic dolerite plateau and occasionally cut through sandstone outcrops. In their lower reaches, the rivers flow through alluvial sand and gravel (Bacon 1984, Department of Mines 1975). The youthful topography of the area is indicated by the steep gradient of the river beds in the upper and middle reaches, where waterfalls occur e.g. Hardings Falls on the Swan River. Where the rivers cut through sandstone and dolerite they form steep cliff faces and gorges e.g. Apsley Gorge above Rosedale, and the gorge leading to Hardings Falls on the Swan River.

Predominantly, the Swan River basin is covered with coastal grassy forest (Kirkpatrick and Dickinson 1984), which varies in dominance between Eucalyptus pulchella, E. globulus, E. viminalis, Callitris rhomboidea and Casuarina stricta. At its source, the Swan River catchment is dominated by

Eucalyptus obliqua and E. delegatensis, which are indicative of high rainfall areas. The Apsley River basin has similar forest types, but additionally supports patches of closed heathland and Eucalyptus obliqua-dominated open sclerophyll forest north of Moulting Lagoon. The lower reaches of the Swan and Apsley basins have been largely cleared for agriculture and sheep grazing, though this is by no means a static situation and forest is continually being removed for pasture (see Kirkpatrick and Dickinson 1982). In the upper forested catchment of the Swan River 1985 hectares of forest have been clearfelled, burnt and resown between 1977 and 1985, and 1150 hectares have been similarly treated in the Apsley catchment between 1974 and 1985 (Bennett pers. comm. and unpublished Forestry Commission reports).

3.2.3 Hydrology and water chemistry

The location of the stream gauges used in this study are shown in figure 45. The recorders on the Apsley River upstream of the Coles Bay Road, and on the Swan River at the Grange are water-storage recorders, controlled by a concrete weir, and activated by the motion of a float which is recorded continuously on a chart. A bubble meter and chart recorder were installed on the Swan River at Hardings Falls in July 1983. The instruments continuously record the pressure required to maintain a small flow of gas from an orifice submerged in the stream. A natural low-water control is used at this station, where the stream forms a small rapid on dolerite. Plates 1 and 2 illustrate the gauge sites during low and high flows respectively.

Figures 46, 47 and 48 represent hydrographs for the Swan River at the Grange, the Swan River at Hardings Falls and the Apsley River upstream of the Coles Bay Road respectively. The hydrograph for 1983 has been included for each of the three stations to illustrate hydrological conditions antecedent to the study period (February 1984 to June 1986). The magnitude of peak and low average daily

Plate 1. Gauge sites at

A Swan River at the Grange (28/7/83)
$0.874\ m^3\ s^{-1}$

B Apsley River u/s of Coles Bay Road (12/8/83)
$0.168\ m^3\ s^{-1}$

C Swan River at Hardings Falls (13/8/83)
$0.073\ m^3\ s^{-1}$

Discharges are average daily flows

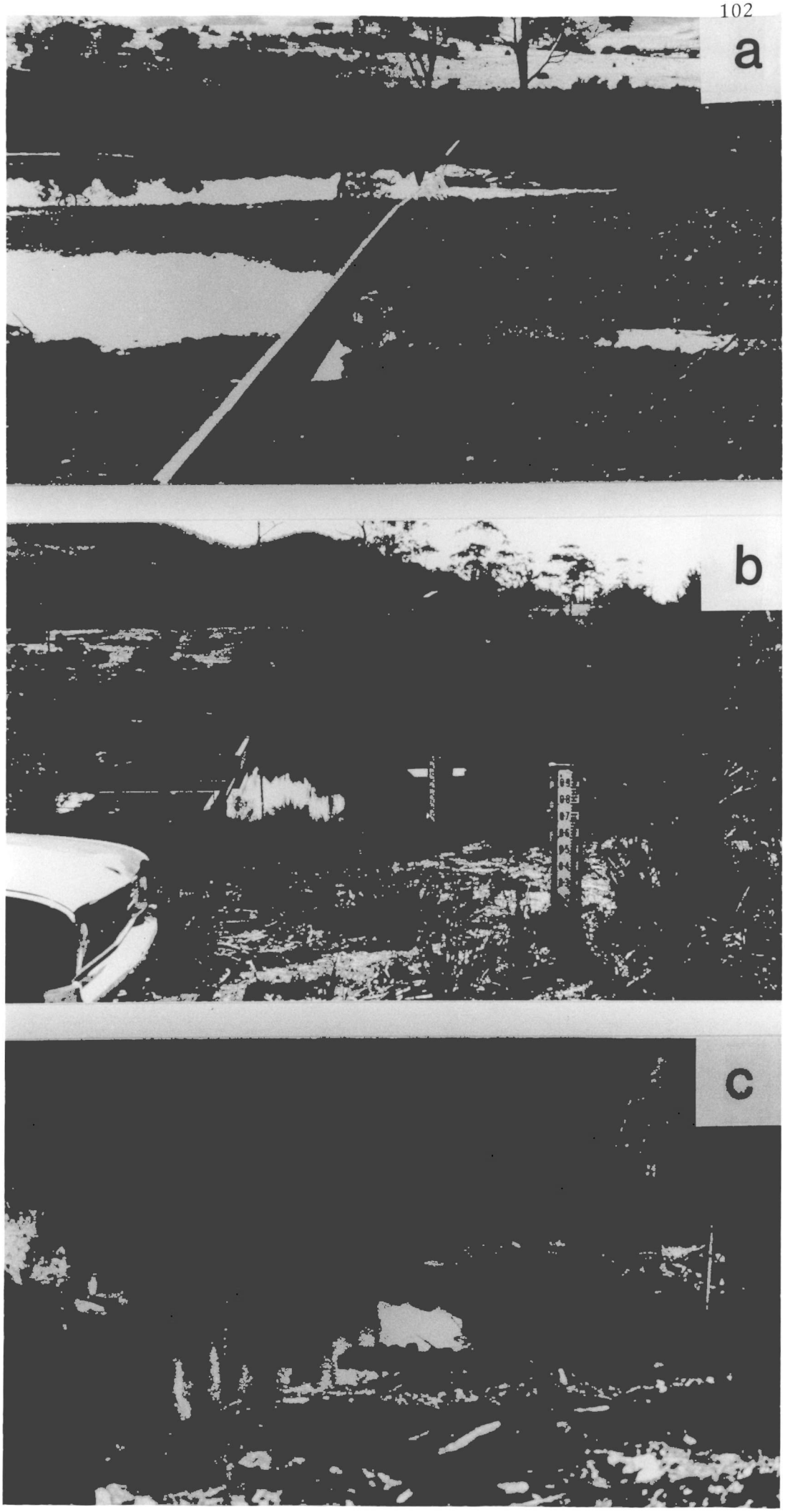
Plate 2. Gauge sites at

A Swan River at the Grange (29/7/84)
$298.45\ m^3\ s^{-1}$

B Apsley River u/s of Coles Bay Road (29/7/84)
$121.73\ m^3\ s^{-1}$

C Swan River at Hardings Falls (28/8/83)
$2.5\ m^3\ s^{-1}$

Discharges are average daily flows


a
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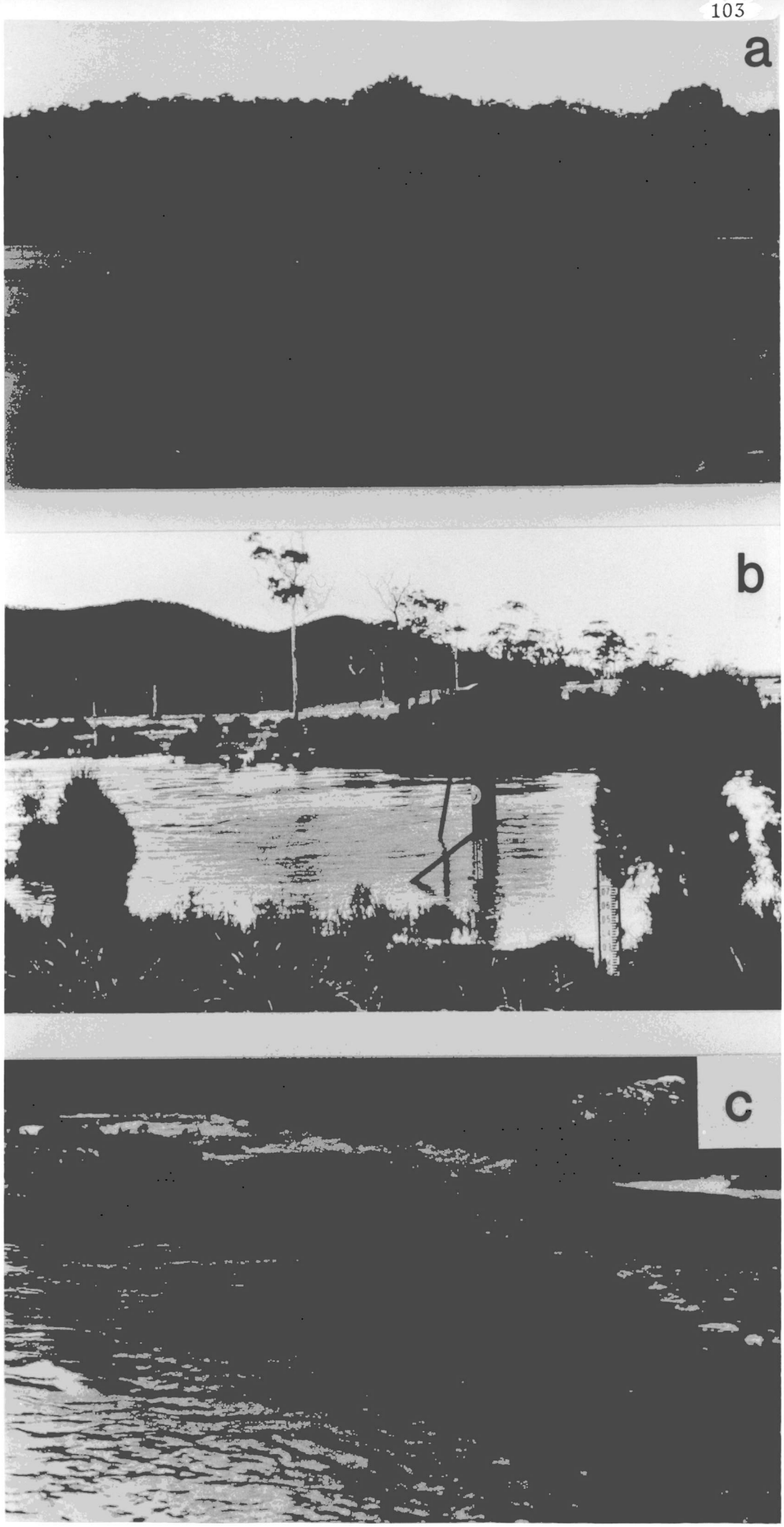
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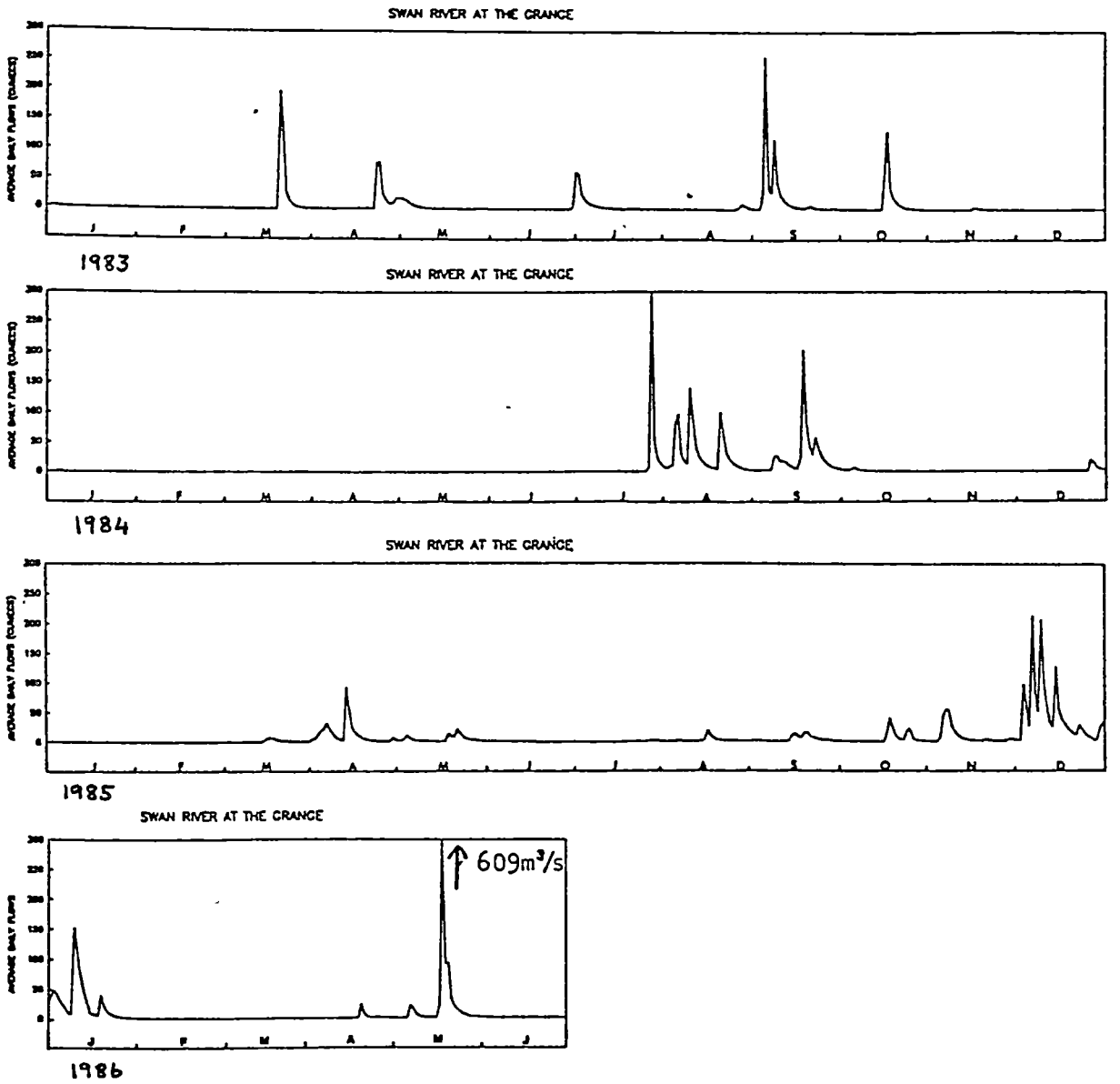


Fig. 46. Hydrograph (average daily flows) for the Swan River at the Grange from January 1983 to June 1986. Discharges are in cumecs

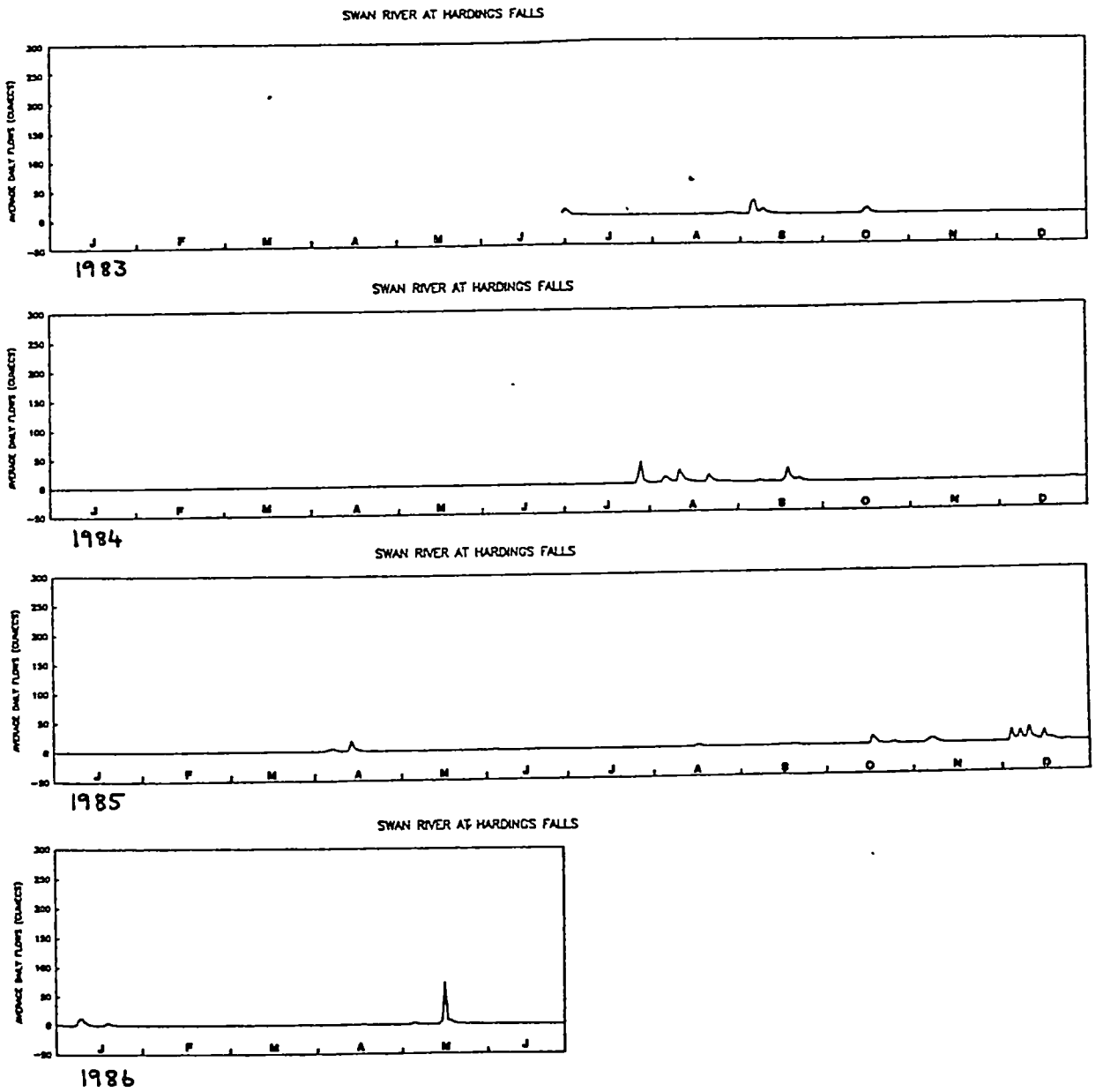


Fig. 47. Hydrograph (average daily flows) for the Swan River at Hardings Falls from January 1983 to June 1986. Discharges are in cumecs

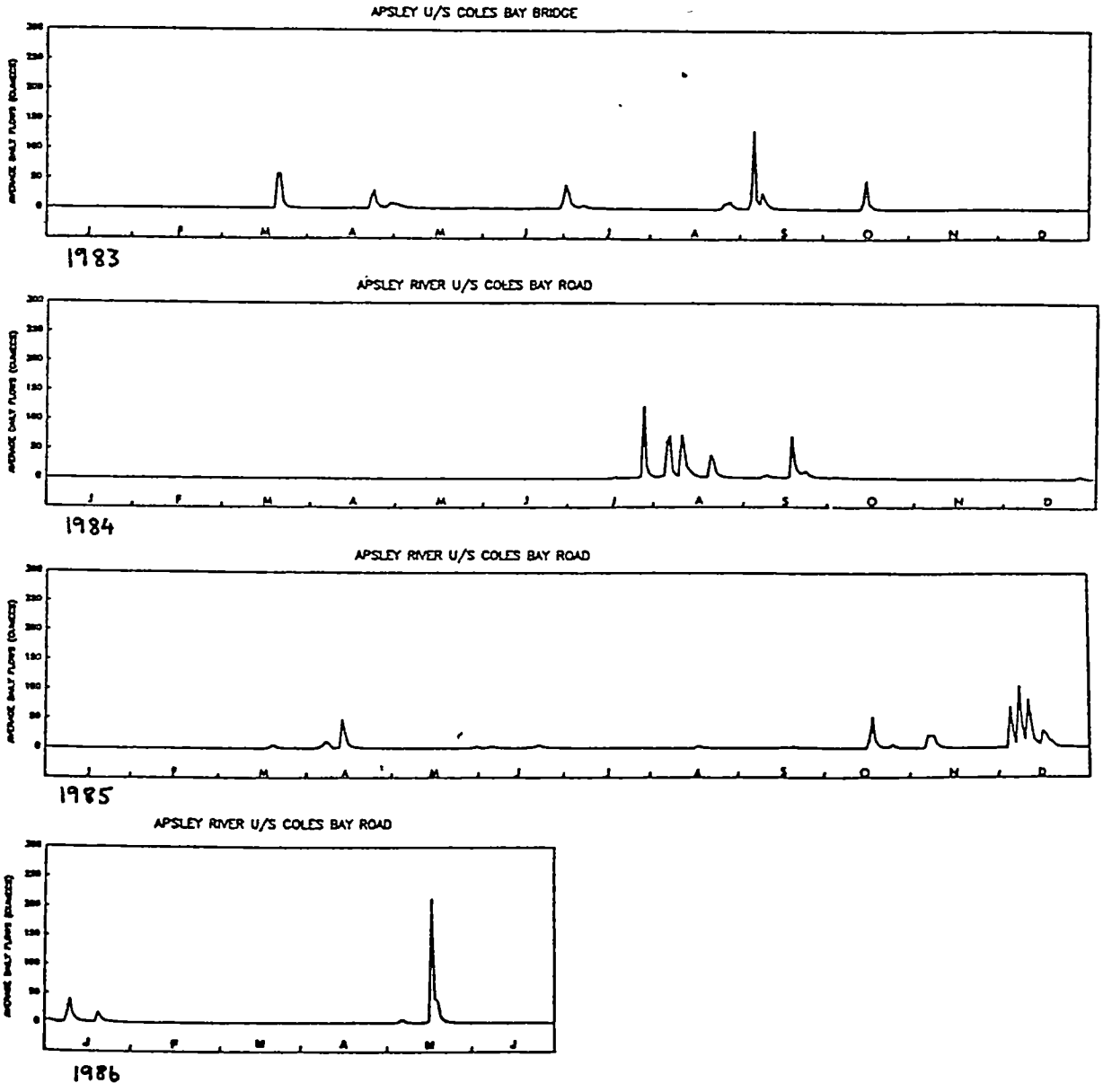


Fig. 48. Hydrograph (average daily flows) for the Apsley River u/s of the Coles Bay Road from January 1983 to June 1986. Discharges are in cumecs

flows for the annual series (and, where available, peak instantaneous flow in parenthesis) for each of the stations during the study period may be summarized as follows:

	Swan (Grange)	Swan (Hardings Falls)	Apsley
Basin area (km^2)	448.0	36.4	155.0
Maximum average daily flow (Q m^3/s)			
1983	257.3 (866)	24.17 (159)	131.6 (338)
1984	298.45 (617)	38.00 (92)	121.73
1985	211.1 (388)	25.25	105.37
1986 (6 months)	609.02 (1172)	73.03 (198)	213.21(326)
Minimum average daily flow (Q m^3/s)			
1983	0.01	0.03	0
1984	0.0067	0.009	0
1985	0.05	0.017	0.001
1986 (6 months)	0.13	0.029	0.029

As expected from the catchment area, peak discharges for the Swan River at the Grange are approximately 10x larger than for the Swan River at Hardings Falls. Peak discharges for the Apsley River are 2-3x smaller than for the Swan River at the Grange. Minimum flows are close to zero for all three stations. During the study period there were 13 hydrological events with discharges greater than 50 m^3/s for the Swan River at the Grange. The Swan River at Hardings Falls and the Apsley River experienced 16 and 13 events greater than 17.3 m^3/s and 4.07 m^3/s respectively. These comparative discharge figures were obtained by using specific flows (i.e. discharge/catchment area). The hydrographs clearly demonstrate the variable hydrology of the rivers, and the consequent high coefficients of variation of hydrological events. Percentage time per annum of particular discharges for the Swan River at the Grange is as follows:

	<0.1 cumecs	0.1 to 50 cumecs	>50 cumecs
1984 (from 20/2)	34%	63%	3%
1985	6%	90%	4%
1986 (to 1/6)	0	96%	4%
Total for study period	15%	81%	4%

In order to put the annual series data collected during the study period into perspective, a flood frequency curve using the partial series for the entire record was established for the Swan River at the Grange (G1) and the Apsley River upstream of the Coles Bay Road (G3) (see Pattison 1977 for details of this procedure). The partial series is preferable to the annual series when frequent peak events are being considered, and can indicate the probability of events being equalled or exceeded 2 or 3 times per year. Minor peaks which are associated with a larger flood have not been included in the series for the Swan and Apsley Rivers. The average recurrence interval was calculated using the equation Ti = N + 1 / i, where Ti = average recurrence interval (years), N = number of complete years of record, i = rank of flood in the series (the largest flood having rank i = 1). The partial series data for G1 and G3 are listed in appendix 3, and graphed in figure 49.

Figure 49 demonstrates that the peak discharge in 1986 is the second largest recorded flood for both the Swan and Apsley Rivers, and the peak discharge for 1985 has an 18 month recurrence interval. The least squares models indicate a predicted value of 3548 $m^3 s^{-1}$ ($r^2 = 0.98$, $p < 0.001$) and 832 $m^3 s^{-1}$ ($r^2 = 0.97$, $p < 0.001$) for the 100-year recurrence interval peak for the Swan (G1) and Apsley (G3) Rivers respectively.

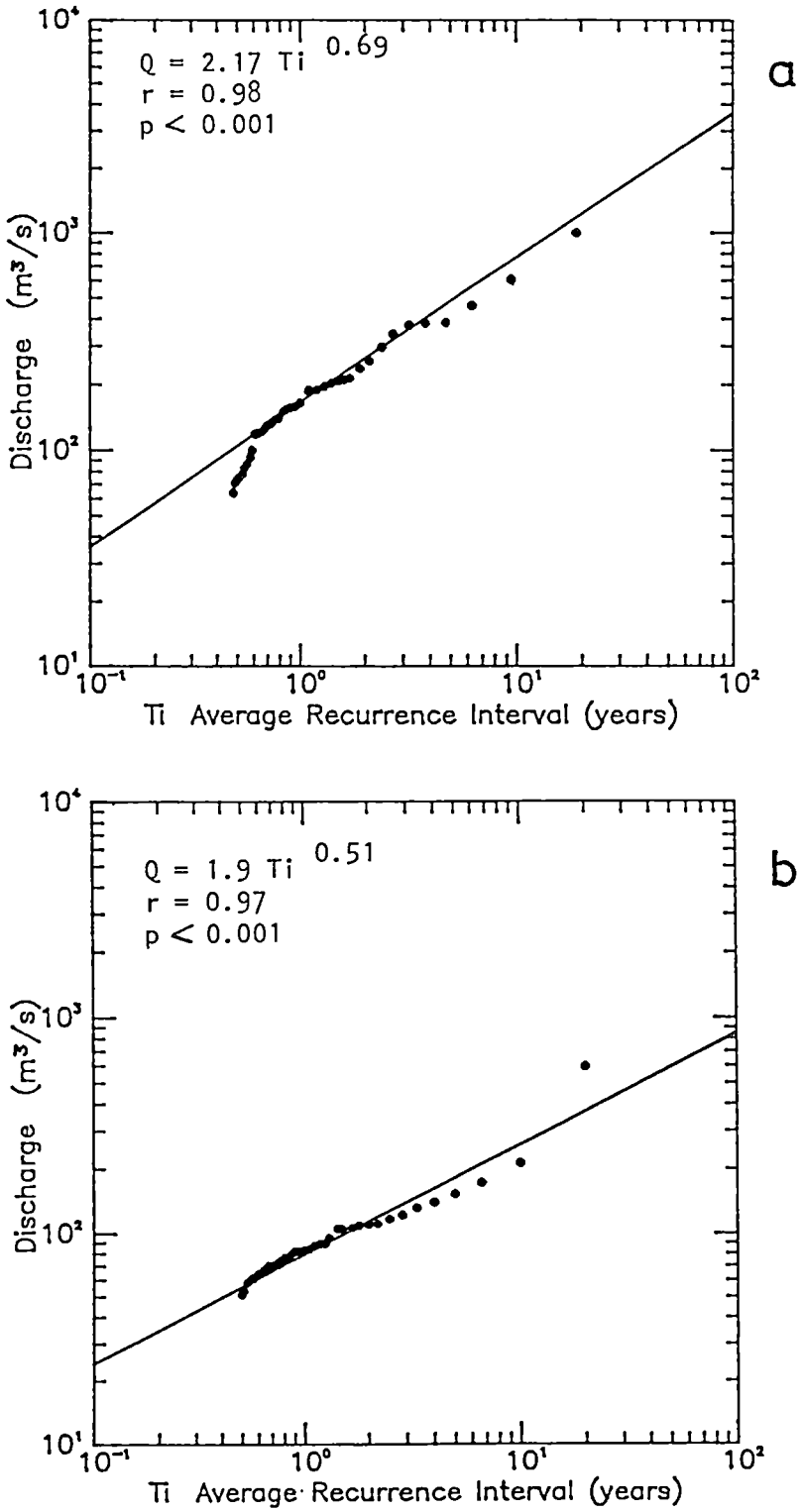


Fig. 49. Flood frequency curve for the partial series. a) Swan River at the Grange, b) Apsley River u/s of the Coles Bay Road

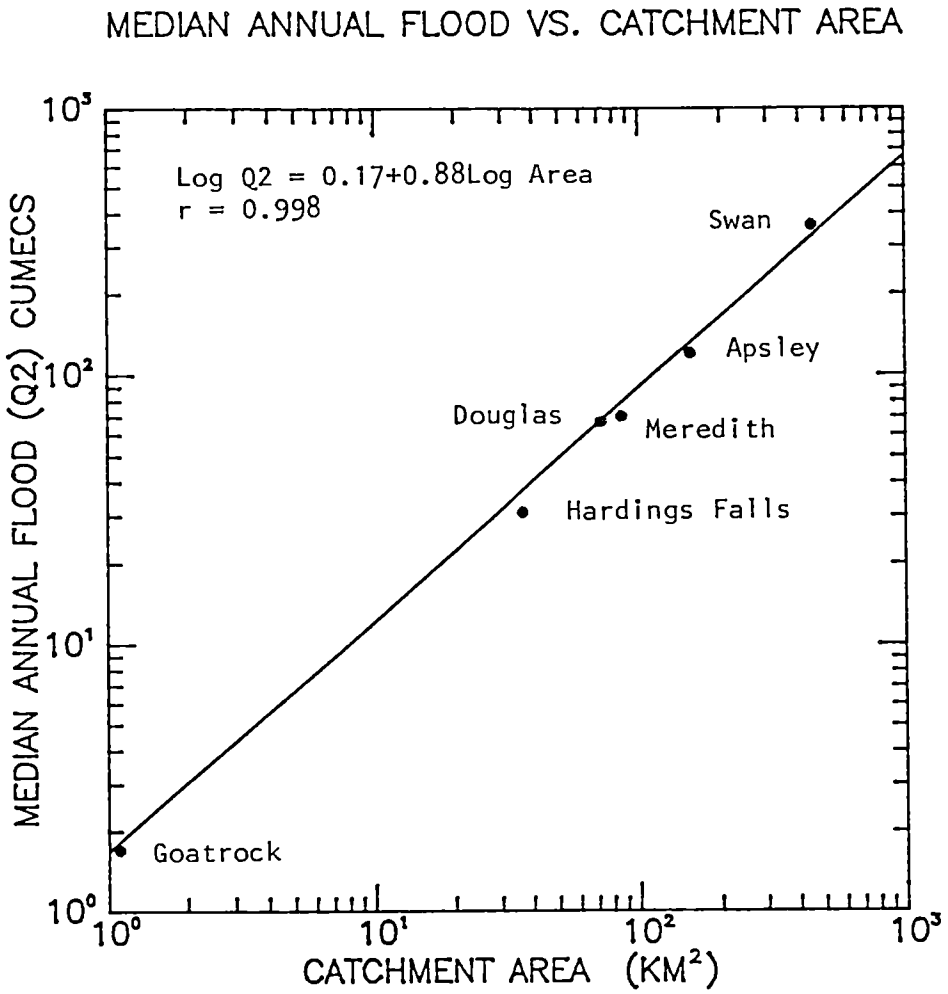


Fig. 50. Median annual flood plotted against catchment area for the central east coast of Tasmania. The gauging stations are on the Douglas River u/s of the highway, Apsley River u/s of the Coles Bay Road, Swan River at Hardings Falls and the Grange, and Meredith River at Goatrock Creek and u/s of the highway

A regional flood analysis was undertaken using annual data from the Swan, Apsley, Douglas and Meredith Rivers (see fig 45). Regional analyses are useful for estimating peak discharges at sites which are distant from a stream gauging station, and may additionally be used where only a short length of record is available at a site. The available length of record may be adequate to derive an estimate of the median annual flood discharge, but too short for calculating the slope or curve of a direct flood frequency analysis (as is the case for the discharge data from the Swan River at Hardings Falls).

Figure 50 shows a plot of catchment area versus median annual flood (Q2) for six gauging stations in the region. The regional flood relationship is a very strong one ($r = 0.998$, $p < 0.001$), and demonstrates that it is possible to extrapolate accurate discharge values at ungauged sites on the central east coast using catchment area alone (table 7). Discharges for ungauged sites in this study have been derived using catchment area ratios.

Water samples were collected for comprehensive analyses from the Swan and Apsley Rivers from July 1983 to December 1984, and were irregularly sampled for selected parameters during 1985. The locations of the sample sites are shown in figure 45. The samples were analysed for pH, temperature, non filterable residue, filterable residue, colour, dissolved oxygen, sodium, magnesium, potassium, calcium, chloride. Methods of analysis are described in section 2.3.2. Additionally, analyses of total nitrogen (Kjeldahl digestion, in p.p.m.), phosphorus (vanado-molybdate method of 1 g digested with $HNO_3/HClO_4$ and absorption read at 400 nm on a Varian Superscan spectrophotometer, in p.p.m.) and turbidity (Jackson Turbidity Units) were undertaken.

Water temperatures vary from 6.0°C in August 1983 for the Upper Swan River to 22.5°C in January 1984 for the Swan

River at Hardings Falls. Diurnal water temperatures for the Swan River at the Grange, measured during high discharges on July 30th 1984, range from 6.5°C to 8.0°C, and during low summer discharges on March 2nd 1984 range from 17.0°C to 18.5°C. Water temperatures for the Apsley River range from 8°C in August 1983 at Rosedale to 19.5°C for all three stations on three separate days in summer. Table 5 summarizes least squares correlations between water temperature and season (October to March samples are termed 'summer', and April to September samples are termed 'winter') for the six sampling sites, and demonstrates significant and strong correlations between season and temperature for all sites. Superimposed on these seasonal trends are hydrological ones. Table 5 displays significant trends between water temperature and discharge with the exception of the Swan River at Hardings Falls and the Upper Swan River. Both these sampling sites are in the headwaters of the river, where riparian vegetation shades out sunlight. Negative correlations exist for the other sites, with increasing discharge lowering the temperature of the water. Temperature change of the Apsley River at the Causeway and at Rosedale does not vary as significantly with discharge as the Apsley River at the weir. It appears that the effect of variable discharge on water temperature increases away from the source, attaining the greatest impact towards the mouth.

Both rivers display essentially neutral pH. The lowest pH values occur during high discharges (table 5) and values range from 6.3 to 8.1. Again, discharge appears to affect the variability of pH to a far greater extent downstream (see levels of significance in table 5). The relation between pH and season is consistently insignificant, with the exception of the Swan River at the jetty. This latter exception may be due to the low sample number (N=3) and the influence of tidal seawater. Norris et al. (1980) found highly significant temporal variation of pH at eight sites along the South Esk River in Tasmania and pH was positively correlated with flow rate.

	Jetty Road 1	Grange 2	Hardings Falls 3	Upper Swan 4	Apsley weir 5	Causeway 6	Rosedale 7	Dependent variable
Temperature		0.01 -ive	N.S.	N.S.	0.01 -ive	0.10 -ive	0.10 -ive	Discharge
		0.001 -ive	0.01 -ive	0.001 -ive	0.001 -ive	0.001 -ive	0.001 -ive	Season
pH	0.001 -ive	0.001 -ive	0.05 -ive		0.01 -ive	0.10 -ive	N.S.	Discharge
	0.02 -ive	N.S.	N.S.		N.S.	N.S.	N.S.	Season
Non filterable residue	0.10 +ive	N.S.	N.S.		N.S.	0.10 +ive	0.10 +ive	Discharge
	N.S.	N.S.	N.S.		0.10 +ive	0.001 +ive	0.001 +ive	Season
Filterable residue	N.S.	0.02 -ive	0.01 -ive	0.001 -ive	N.S.	N.S.	N.S.	Discharge
	N.S.	N.S.	N.S.	N.S.	N.S.	0.02 -ive	N.S.	Season
Colour	0.001 +ive	0.001 +ive	0.10 +ive		0.001 +ive	0.05 +ive	0.05 +ive	Discharge
	N.S.	N.S.	N.S.		N.S.	0.001 +ive	0.001 +ive	Season
Dissolved oxygen		0.01 +ive	N.S.	N.S.	0.02 +ive	0.10 +ive	N.S.	Discharge
		0.001 +ive	0.001 +ive	0.10 +ive	0.01 +ive	0.001 +ive	0.01 +ive	Season
Turbidity	0.05 +ive	0.001 +ive	N.S.		0.01 +ive	0.05 +ive	0.001 +ive	Discharge
	0.02 +ive	N.S.	N.S.		N.S.	0.02 +ive	0.10 +ive	Season

Table 5. Significance levels (p) of least squares correlations between season, discharge and some basic water characteristics for 7 sites on the Swan and Apsley Rivers (N.S. = not significant)

Values of non filterable residue vary from 7.0 p.p.m. for the Swan River at the Grange on July 29th 1984 to less than 1.0 p.p.m. recorded at all the sampling sites at all times of the year. Least squares correlations between non filterable residue and discharge and season for six stations are listed in table 5. The results display some interesting trends. The Apsley River consistently has a greater suspended load in winter than summer, compared to the Swan River which displays no seasonal patterns in non filterable residue for any of the sampling sites. That is, high levels of suspended sediment for the Swan River may occur at any time of the year. The relationship between discharge and non filterable residue also displays unusual inconsistencies. The Swan River at the Jetty Road shows positive tendencies towards increased suspended sediment with discharge, however the other two sites have insignificant correlations. The Apsley River at the Causeway and at Rosedale display higher levels of non filterable residue during high flow than during low flow. The pattern does not occur for the Apsley River at the weir.

It is logical to suppose a positive correlation between discharge and suspended sediment, however Chorley et al. (1984) explain how logarithmic plots of suspended load as a function of discharge are rather misleading, as there are marked timelags between discharge and changes in rates of suspended load. Also, even at a sampling site with a more or less constant debris size, the discharge:suspended sediment association may differ by one or two orders of magnitude. These differences are all dependent on antecedent hydrological conditions, on whether discharge is increasing or decreasing, on the state of the banks and on the season of the year. The lack of constancy in sediment:discharge relationships is reflected in the numerous equations which have been developed relating these two variables (Vanoni 1975, Olive and Rieger 1984).

In the case of the Swan and Apsley Rivers, it is only possible to broadly speculate on the results for non filterable residue. Specific peak values for the Apsley River are unusually high for the region (see chapter 2), indicating that erosional processes (and hence suspended sediment) may react accordingly. Flood samples were usually collected after the flood peak and often during falling water levels. It thus appears that there is a time lag between discharge and changes in suspended load for the Swan River. Additionally, lack of relationship for the Swan River may be due to the larger proportion of the catchment being utilized for agriculture and forestry activities compared to the Apsley River basin. Three gravelled roads cross the Swan River upstream of the junction with the West Swan River, and Michaelis (1984), in a review of the effects of forestry activites on inland waters of Tasmania, has pointed out that roading activities are the greatest contributor to levels of suspended sediment in streams. Additionally, clearing of riparian vegetation by farmers greatly contributes to atypical levels of suspended sediment.

By contrast, turbidity appears to be a more sensitive indicator of suspended load for the Swan and Apsley Rivers insofar as there is little lag time between increases in discharge and increases in turbidity. Turbidities range from 0.5 to 22 J.T.U.s for the Swan River and 1.0 to 35 J.T.U.s for the Apsley River, and increase with increasing discharge for all sampling sites with the exception of the Swan River at Hardings Falls.

Values of filterable residue range from 25 p.p.m. for the Upper Swan River to 234 p.p.m. for the Swan River at the jetty road. There is a trend from low to high levels of filterable residue from the headwaters to the mouth of both the Swan and Apsley Rivers. Ranges for the Apsley River are 38 p.p.m. for the Apsley River at Rosedale to 290 p.p.m. for the Apsley River at the weir. The correlations between

discharge, season and filterable residue are poor. In theory dissolved load reaches a concentration peak at relatively low discharges, and thereafter concentration decreases with increasing discharge (Leopold et al. 1964). In practice, the Apsley River displays insignificant correlations between discharge and filterable residue, and only the Apsley River at the causeway displays any correlation with season (table 5). Filterable residue increases as discharge decreases for all sampling sites on the Swan River, except for the Swan River at the jetty road. Samples taken at this latter site are probably influenced by tidal influxes of seawater.

A colour range of 5 to 100 hazen units was recorded at each of three sampling sites along the Swan River. The range for the Apsley River is from 5 hazen units (recorded at all three stations) to 85 hazen units recorded at the weir. Colour appears to vary significantly with discharge at all six sampling sites (table 5), resulting in an increase of colour with discharge. There is, however, little relationship between colour and season, with only the Apsley River at the causeway and at Rosedale showing a trend towards higher colour values in winter.

Values of dissolved oxygen are consistently high along both rivers and throughout the study period. The range for the Swan River is 9 to 13 mg/l, and for the Apsley River 8 to 13 mg/l. Variability of dissolved oxygen is seasonally dependent (table 5), with higher values experienced during winter. Superimposed on this seasonal trend is discharge variability. Least squares correlations between discharge and dissolved oxygen are not consistent, but a positive relationship occurs for the Swan River at the Grange, and the Apsley River at the weir and causeway.

As expected, seasonal variation of temperature and dissolved oxygen are very similar: levels of dissolved oxygen increase as temperature decreases in winter. The reverse is true during summer. There also appears to be some relationship between pH and colour, both being related to discharge.

Increasing colour values during high discharges correspond to a decrease in pH (or acidification). This lack of seasonality in pH and colour reflects aseasonality of hydrological events for the Swan and Apsley Rivers (see chapter 2).

Sampling for total nitrogen (N) and total phosphorus (P) was undertaken at the Swan River at the Grange and Hardings Falls and at the Apsley weir only. Values of P range from <0.010 to 0.006 p.p.m. for both the Swan and Apsley Rivers. Values of N range from 0.08 to 0.43 p.p.m. for the Apsley River and 0.04 to 0.59 p.p.m. for the Swan River. P and N appear to increase with increasing discharge for the Swan River (table 6), but there is no significant correlation for the Apsley River. Seasonal trends are not apparent for either river.

Chloride ions increase away from the source for both rivers. For example on June 17th 1984, Cl^- values for the Swan River ranged from 254 to 479 to 677 p.p.m. at the Upper Swan, Hardings Falls and the Grange respectively. On August 4th 1984, values of Cl^- for the Apsley River ranged from 395 to 536 to 902 p.p.m. at Rosedale, the causeway and Apsley weir respectively. Seasonal variations of Cl^- are not significant (table 6) and chloride ions display an inverse relationship with discharge, decreasing as discharge increases. The Apsley River at the causeway and Rosedale are exceptions to this trend, with little variation recorded at the causeway, and no variation at Rosedale.

Cationic composition also displays some significant variations (table 6). Calcium is negatively correlated with discharge, with the exception of the Swan River at the jetty which is positively correlated. There are no significant variations of this cation with season. Magnesium is inversely correlated with discharge and displays little or no variation with season. Potassium and sodium were sampled at two sites only. Sodium concentrations vary inversely with discharge for the Swan River at the Grange and show no

	Jetty Road 1	Grange 2	Hardings Falls 3	Upper Swan 4	Apsley weir 5	Causeway 6	Rosedale 7	Dependent variable
Total Nitrogen (N)		0.05 +ive	0.10 +ive		N.S.			Discharge
		N.S.			N.S.			Season
Total Phosphorus (P)		0.10 +ive	0.05 +ive		N.S.			Discharge
		N.S.			N.S.			Season
Ca^{2+}	0.01 +ive	0.001 - ive	0.01 -ive		0.001 -ive	N.S.	0.01 -ive	Discharge
	N.S.	N.S.			N.S.	N.S.	0.10 -ive	Season
Mg^{2+}	N.S.	0.001 -ive	0.001 -ive		0.05 -ive	0.01 -ive	0.10 -ive	Discharge
	N.S.	N.S.			N.S.	0.10 -ive	N.S.	Season
Na^{+}		0.05 -ive			N.S.			Discharge
		N.S.			N.S.			Season
K^{+}		N.S.			N.S.			Discharge
		0.05 -ive			0.01 -ive			Season
Cl^{-}	N.S.	0.001 -ive	0.10 -ive		0.02 -ive	N.S.	N.S.	Discharge
	N.S.	N.S.			N.S.	N.S.	N.S.	Season

Table 6. Significance levels (p) of least squares correlations between season, discharge and chemical characteristics for 7 sites on the Swan and Apsley Rivers (N.S. = not significant)

significant correlation for the Apsley River. Variations between discharge and potassium are insignificant, but this cation appears to decrease in concentration during winter.

Chloride concentrations for the lower reaches of the Swan and Apsley Rivers are high, and are comparable with those of the Coal River (see Table 3). The mean Cl^- value for the Apsley River at the weir from 15th August 1983 to 22nd January 1985 is 866 p.p.m., and for the Swan River at the Grange during the same period is 523 p.p.m. Insufficient data prevent complete stoichiometric analysis to be undertaken, but from the above data it can be assumed that chloride is the dominant anion, while sodium is the dominant cation throughout the catchments. Seawater stoichiometries are to be expected in regions that have little precipitation and high evaporation. However, it was expected that this pattern would be different in the headwaters of the Swan and Apsley Rivers, which experience high precipitation. It is possible that steep, rocky, doleritic headwaters with thin soils experience immediate runoff and are not conducive to substantial groundwater inputs (see values for serial correlation coefficient in chapter 2). Additionally, easterly weather systems account for the majority of rainstorms on the east coast of Tasmania, and these would deposit precipitation rich in sea salts throughout the catchments.

In brief, during high hydrological events the Swan and Apsley Rivers experience the following physical and chemical changes: temperature and pH decrease while turbidity, colour and (inconsistently) dissolved oxygen increase; non filterable residue increases along the Apsley River but not the Swan River (though this probably reflects the inadequacies of the sediment rating model), and the inverse is true for filterable residue along the Swan River; total phosphorus and nitrogen increase for the Swan River (but not the Apsley); chloride and cations decrease with the exception of K^+ which shows no significant variation. The reverse trends are found during low flows.

Seasonal variations are apparent for water temperature which is high in summer and low in winter. Dissolved oxygen is high during winter. There is no trend with season for pH, colour and filterable residue and little trend for turbidity. Non filterable residue is greater in winter than summer for the Apsley River only. Anions, cations, total phosphorus and total nitrogen display no seasonal trend, with the exception of K^+ which tends to decrease in winter. Insignificant seasonal trends are probably due to the seasonally erratic behaviour of peak and low hydrological events.

3.3 Methods

3.3.1 Permanent plot selection

Fourteen 2x2 metre permanent plots were established along the Swan and Apsley Rivers (see fig 51) in order to investigate vegetation dynamics after high and low flow events. Each plot was marked with four wooden stakes which were replaced when necessary after a peak flow event. The locations of the plots were chosen as representative of the varying hydrological and chemical conditions to be found along the rivers, and where there were suitable communities of aquatic angiosperms. The characteristics of each plot are summarized in table 7.

3.3.2 Recording within the plots

Several methods can be used for studying changes in abundance of aquatic angiosperms (Hellawell 1978). Measurements of biomass and productivity (Edwards and Owens 1960, Dawson 1976a) are not appropriate where repeated observations of the same plot are required, especially

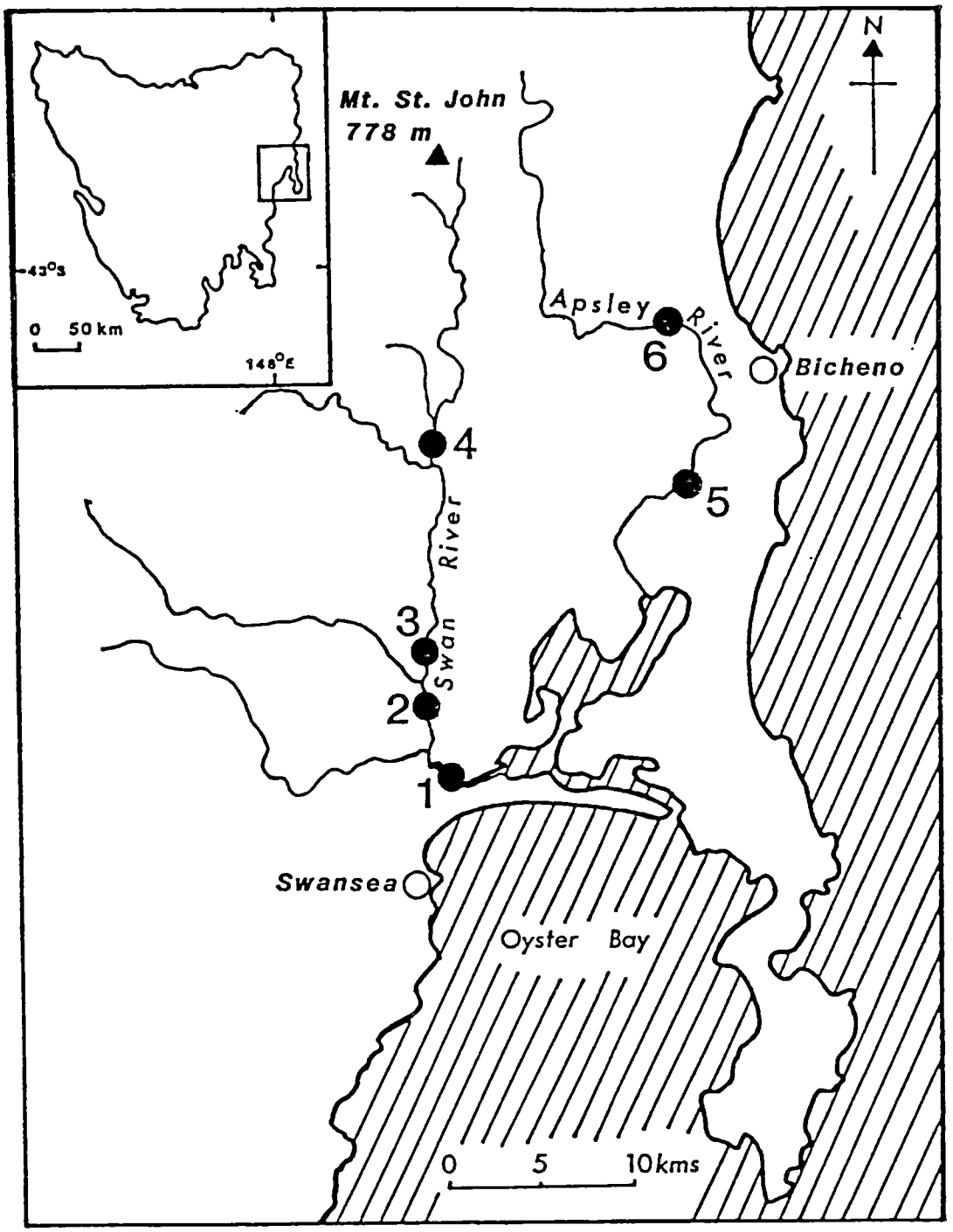


Fig. 51. The location of the 14 permanent plots. The plots are distributed between the 6 sites as follows: Site 1, Plots 1 - 4; Site 2, Plots 5 - 8; Site 3, Plot 9; Site 4, Plot 10; Site 5, Plots 11 - 12; Site 6, Plots 13 - 14

				Grid Reference	Basin Area (km^2)	Mean species richness	Altitude	Substrate	Average annual discharge (m^3/s)	Mean filterable residue (p.p.m.)	% permanent water cover
I	Lower Swan River at Jetty Road	1. start of transect; along foot path	Freycinet	903404	640	6.56	5m	rocks & silt	6.500	184	100
		2. jetty before outcrop	1:100,000	905403	640	4.83	5m	sand & silt	6.500	184	100
		3. west corner boat ramp	topographic	907403	640	5.17	5m	fine silt	6.500	184	100
		4. east corner boat ramp	survey sheet 8513	907403	640	5.17	5m	fine silt	6.500	184	90
II	Swan at the Grange	5. by intake pipe	"	890444	448	8.28	10m	fine silt	4.877	86	60
		6. overflow channel by weir	"	890443	448	9.89	10m	pebbles & silt	4.877	86	40
		7. by weir proper	"	890443	448	9.56	10m	pebbles & silt	4.877	86	80
		8. between weir and pipe at stump	"	890443	448	5.56	10m	pebbles & silt	4.877	86	80
III	Swan at Gala	9. causeway	"	891488	251	2.11	15m	pebbles	3.000	75	20
IV	Swan at Waters Meeting	10. upper catchment	Break O'Day 1:100,000	893577	88	1.78	60m	rocks & boulders	1.250	39	30
V	Apsley U/S Coles Bay Rd	11. weir	topographic	025561	155	9.78	10m	clay/silt	1.975	120	80
		12. rocks D/S weir	survey sheet 8514	024561	155	4.11	10m	rocks & silt	1.975	120	70
VI	Apsley Causeway	13. at inlet stream	"	028648	100	3.61	40m	sand/gravel	1.400	72	20
		14. floodplain by outlet	"	028648	100	7.50	40m	sand & silt	1.400	72	10

Table 7. Characteristics and specific location of the 14 permanent plots

where, as in this study, there are no extensive areas of homogenous vegetation. An alternative approach is cover mapping, an established technique in terrestrial ecology (Greig-Smith 1964, Mueller-Dombois and Ellenberg 1974, Priestley 1913) that has been applied to river ecosystems in only a few cases (Ham et al. 1981, Wright et al. 1981, Jones 1955). Although biomass and cover do not necessarily show a simple linear relationship for aquatic angiosperms (Dawson 1976a) percentage cover is considered a good measure of plant abundance.

Percentage cover of each species was recorded and calculated by mapping the area of the uppermost layer of vegetation on to graph paper. The plots were additionally checked for 'understorey' species. Notes were taken on the growth or recession of individual plants, but this was not possible for dense stands of emergent monocotyledons such as Juncus articulatus or Juncus kraussii, or dense mats of submerged angiosperms. The plots were checked 18 times between February 1984 and June 1986. Sampling was less frequent during 1985 and 1986 and occurred after high or low flow events.

Except where authorities are given, nomenclature of plant species follows Curtis (1963, 1967), Curtis and Morris (1975), Willis (1970), Aston (1973), Sainty and Jacobs (1981), Robertson (1984) and Orchard (1985).

3.3.3 Data analyses

The plot data were divided into summer and winter and into high, low or steady discharges for examination of some features of community structure and dynamics. Percentage plant cover of each plot was normalized by log10 transformation (May 1975, Pielou 1975, 1977). The richness of species (S), the reciprocal of Simpson's index (N_2) (Hill 1973), beta turnover (β_T) and a modification of Pielou's evenness (J) (Pielou 1975) were computed for each plot in time.

The reciprocal of Simpson's index was calculated using $N_2 = (\Sigma x)^2 / \Sigma (x^2)$, where x= % cover of each species. N_2 is considered by Hill (1973) and Peet (1974) to be a more representative and meaningful measure of ecological diversity than the widely used Shannon-Wiener index (Shannon and Weaver 1949). Effectively, N_2 is a measure of the degree of species polydominance with the maximum attainable value being n (where n = the number of species present on the plots at the specific recording times) when all species have identical cover. If only one species has any appreciable cover, N_2 will approximate to one.

Beta diversity is used to indicate the extent of species replacement or biotic change along environmental gradients (i.e. species turnover) (Whittaker 1972, 1977, MacArthur 1965, 1972) . Beta diversity was calculated here using $\beta_T = [g(H) + l(H)] / 2\bar{\alpha}$ (Wilson and Shmida 1984). β_T (beta turnover) combines the idea of species turnover reflected by gain (g) and loss (l) of species along the environmental gradient (H) (in this case H is a time gradient), with a standardization by average sample richness ($\bar{\alpha}$). Turnover was examined between consecutive samples in time.

A modified version of the Pielou (1975) index was used to measure evenness (J') (Hill 1973). The diversity of a community depends on the number of species present and the evenness with which the individuals are apportioned among them. Thus, describing a community solely in terms of a diversity index confuses these two factors (Pielou 1975). Lloyd and Ghelardi (1964) defined evenness as a comparison between diversity as measured by the total number of species, and diversity as measured by an other statistic. J' is here defined as the ratio of N_2 / log N_0 , where N_2 = reciprocal of Simpson's index and N_0 = number of species in the community.

Differences in % cover, richness, diversity, beta turnover and evenness of aquatic angiosperms (dependent variables)

were examined with respect to site, season and hydrology (independent variables) using three-way analysis of variance (SPSSX 1986). October to March samples were termed 'summer', and April to September samples were termed 'winter'. Discharges were divided into high (>50 m^3/s), low (<0.1 m^3/s) and steady (0.1< Q <50 m^3/s). These discharges are for the Swan River at the Grange, and comparative discharges were calculated for the other sites using catchment area ratios (see table 7).

If plot x time data from a community are ordinated, and the time trajectories of each plot traced through the species space of the ordination, then the occurrence of a general successional pattern can be established (Austin 1977). If the majority of plots display parallel or similar trajectories then a general trend is evident; if there is a random distribution of the trajectories there may be no trend or a number of different site-dependent trends. If individual plots show no consistent trajectory then it is likely that there are no temporal patterns operating.

Detrended correspondence analysis was used to ordinate the 252 samples (DECORANA; Hill 1979a). This method has been considered to be superior to other ordination techniques in community ecology (Gauch 1982). However Minchin (1987) has demonstrated a lack of robustness in this currently popular method of ordination. Detrended correspondence analysis ordinations often exhibit marked distortions due to the properties of the implied dissimilarity measure or to the activities of rescaling. Non metric multidimensional scaling has been shown to outperform other ordination techniques (Minchin 1987, Kenkel and Orloci 1986), though the technique has the disadvantage of being uneconomical in terms of computing time and memory requirements. It was not possible to use non metric multidimensional scaling due to the size of the data matrix (252 samples x 30 species).

In addition, the 252 samples were classified using two-way indicator species analysis (TWINSPAN; Hill 1979b) which is a

polythetic divisive method of classification and has been recommended for hierarchical classification because of its effectiveness and robustness (Gauch 1982). If aquatic plant species are differentially distributed within a catchment, and if differences in distribution remain relatively constant over time, then samples from a single site over time should group together. Conversely, if distributions within a catchment change considerably, samples from a single site over time would not group together.

The 250 x 30 matrix was used to examine dissimilarity between consecutive samples in time for each plot. The measure of absolute Euclidean distance was employed where the distance between x and y $= \sqrt{[\sum_i (x_i - y_i)^2]}$ (SPSSX 1986). Dissimilarity decreases as values tend towards zero. Associations between absolute dissimilarity in each plot were explored using the Pearson product moment correlation coefficient and a plot constellation diagram was derived from the data.

In order to obtain some idea of the directionality of change within plots over time, angles between consecutive points on the ordination trajectories were measured. The greatest possible change in direction is produced by an angle of 180°. The smallest change in direction i.e. a stationary point, is produced by an angle of 0°. All angles were measured between the 18 points on the 14 trajectories (i.e. 16 angles per plot) and divided into four categories 0°- 45°, 45°- 90°, 90°- 135°, 135°- 180°. A Kolmogorov-Smirnov test was undertaken to test whether directionality differed from a random distribution. In this case the random distribution was taken as the probability of 4/16 angles falling into each category. Thus the expected distribution of 4 was tested against the observed distribution for each category.

Similarly, a Kolmogorov-Smirnov test was undertaken to test whether the angle of direction of trajectories at each time period differed from a random distribution. The observed distribution for each category was tested against an expected distribution of 3.5 (14 angles per time period). A comparison of the directionality of the 14 plots was undertaken using the Pearson product moment correlation coefficient.

3.4 Results

3.4.1 The aquatic flora

29 species of aquatic angiosperm and one species of algae (Nitella sp.) were recorded in the 14 permanent plots between February 1984 and June 1986. The 29 species of angiosperm are further divided into 11 dicotyledons and 18 monocotyledons, and all belong to 15 families:

Dicotyledons		Monocotyledons	
Compositae	1	Cyperaceae	5
Haloragaceae	3	Gramineae	1
Lobeliaceae	1	Juncaceae	2
Menyanthaceae	2	Juncaginaceae	1
Ranunculaceae	1	Potamogetonaceae	6
Scrophulariaceae	2	Typhaceae	1
Umbelliferae	1	Zanichelliaceae	1
		Zosteraceae	1

Table 8 lists the residence time (as a percentage) of each species in each plot. Percentage times could not be calculated for species with one record only. In the plots where they occurred, species such as Myriophyllum salsugineum, Juncus kraussii, Eleocharis sphacelata, Eleocharis acuta and Scirpus fluitans were recorded during the entire study period. Conversely, species such as Myriophyllum pedunculatum, Potamogeton perfoliatus and Lepilaena cylindrocarpa were recorded for a part of the period only.

Table 9 describes the aquatic species growing in the plots in terms of lifeform, propagative strategy and growth biology. The geographical distributions of the species are also listed. The lifeform classification used is that of Hutchinson (1975), though other schemes exist for describing aquatic plants (see Sculthorpe 1967, Haslam 1978, Westlake 1975). All the species exhibit some morphological adaptation

		Plot	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Species															
•	1	Myriophyllum salsugineum	100	100	100	100	100		100	100						
	2	Ruppia polycarpa	56.5													
	3	Lepilaena cylindrocarpa	95.1	95.1	68.6	37.8										
•	4	Juncus kraussii	100			100										
	5	Baumea arthrophylla	100		43.3											
	6	Potamogeton pectinatus	100	100		100	72.5			65.7						
•	7	Eleocharis sphacelata	100					100	100				100			100
	8	Zostera muelleri		83.6	100	80.7										
	9	Ruppia megacarpa		100	100	82.9										
•	10	Phragmites australis			100											
•	11	Eleocharis acuta					100	100					100	100	100	100
	12	Potamogeton australiensis					16.4	95.1		100			100			
•	13	Scirpus fluitans					100		100	100			100	100	100	100
	14	Lilaeopsis brownii					100	100	100				100			72.6
	15	Juncus articulatus					100	65.7	100	100	45.4		100	*		
	16	Triglochin procera					100	100	65.7	100	100	100	100	95.1	100	100
•	17	Potamogeton ochreatus					100	100								
	18	Potamogeton perfoliatus					41.3	34.4	100		56.2		79.0	*		
	19	Isotoma fluviatilis					*						31.3			
•	20	Typha orientalis						100								
•	21	Gratiola nana						100								
•	22	Nitella spp.						100	100							
•	23	Centipeda minima							100							
•	24	Scirpus nodosus							100							
	25	Myriophyllum simulans										72.6	100	100		
	26	Myriophyllym pedunculatum										16.4		*	45.4	27.4
	27	Nymphoides exigua											80.7			
•	28	Ranunculus rivularis														100
	29	Villarsia reniformis														56.2*
•	30	Gratiola latifolia														100

Table 8. Residence time of each species per plot (% of total study period). * denotes one record only. • denotes species resident for the entire study period

Table 9. Description of the aquatic plants growing in the permanent quadrats along the Swan and Apsley Rivers. The table was assembled from sources listed in the last column, as well as personal observations. The lifeform classification follows Hutchinson (1975): B.I Rooted with part of the vegetative structures emerging above the water surface; B.II Rooted with at least some leaves floating; B.III Rooted and submerged. The following abbreviations have been used: Tas = Tasmania; Qld = Queensland; NSW = New South Wales; Vic = Victoria; SA = South Australia; WA = Western Australia; NT = Northern Territory

	Lifeform (after Hutchinson 1975)	Leaf shape	Root system	Dispersal mechanisms and adaptations	Time of flowering and fruiting	Geographical range	References
Myriophyllum salsugineum	B.111 Perennial	Submerged leaves greatly divided (pectinate); emergent leaves entire	Deep rooted mainly at the base. Can produce adventitious roots from submerged nodes	Fragmentation. Produces mericarps	Variable, during summer	Southern distribution in Australia, extending to S-W Australia and S-E New South Wales, Bass Strait Islands and Tas.	Orchard (1985)
Myriophyllum simulans	B.111 Perennial Paludal or aquatic	Submerged leaves pectinate; emergent leaves linear and entire	Short, rhizomatous root stock	Stranding or growth in a terrestrial environment necessary for fruiting. Shoots can grow from old leaf axils. Fragmentation	Variable, if at all	Southern distribution in Australia, extending to S.A. and S-E New South Wales, Tas., Bass Strait Islands	Orchard (1985)
Myriophyllum pedunculatum	B.111 Perennial Mat-forming Paludal or aquatic	All leaves linear and entire	Shallow roots. Stems prostrate, rooting at the nodes	Fragmentation, produces mericarps	November to March (Aston 1973)	South-eastern Australia (N.S.W., Vic., Tas.)	Orchard (1985)
Ruppia polycarpa	B.111 Perennial	Filiform	Turions (perennating organs). Rhizomatous and deep	Spring-like peduncle for pollination. Achene (fruit) does not float	September to April (Aston 1973)	W.A., S.A., Vic., N.S.W., Tas., New Zealand	Jacobs and Brock (1982)
Ruppia megacarpa	B.111 Perennial	Filiform	Rhizomatous and deep	Spring-like peduncle for pollination. Achene (fruit) does not float	September to April (Aston 1973)	W.A., S.A., Vic., N.S.W., Tas., New Zealand	Robertson (1984)
Zostera muelleri	B.111 Perennial	Linear	Rhizomatous and deep	Short vegetative shoots arise laterally from the nodes. Produces ellipsoid seeds which are buoyed by the pericarp. When pericarp ruptures, seed sinks (McComb et al. 1981)	October to March	South eastern Australia, as far north as southern N.S.W., as far west as Edithburgh	Robertson (1984)
Lepilaena cylindrocarpa	B.111 Perennial, and possibly annual	Linear	Rhizomatous, shallow rooted	Fragmentation. Produces achenes	August to November	S.A., Vic., Tas., and brackish inland waters	Robertson (1984)
Potamogeton pectinatus	B.111 Perennial	Thin and linear	Vigorous rhizome system. Deeply rooted, with fleshy tubers	Grows rapidly vegetatively mainly by tubers (a 24 square metre culture produced 36,000 tubers in one growing season). Profuse fruits	Spring to Autumn	All Australian states except N.T.	Sainty and Jacobs (1981)
Potamogeton australiensis	B.11 Perennial	Linear-lanceolate (submerged) to broad-ovate (floating). Floating leaves translucent, submerged ones leathery	Creeping rhizome	Vegetative and by seed (which float away)	October to December (own observations)	W.A., S.A., N.S.W., Vic., Tas.	Aston (1973), Sainty and Jacobs (1981)
Potamogeton ochreatus	B.111 Perennial (or annual)	Linear leaves	Rhizomatous with long trailing stems	Fragmentation and by seed. Occurs erratically and is not a long lasting perennial, though in the Tasmanian study it was resident the entire period	Spring to early summer	All Australian states	Sainty and Jacobs (1981)

	Lifeform (after Hutchinson 1975)	Leaf shape	Root system	Dispersal mechanisms and adaptations	Time of flowering and fruiting	Geographical range	References
Typha orientalis	B.1 Perennial	Long, linear blade closely enveloping the stem	Rhizomes extensive and deep	Wind dispersed seeds (up to 20,000 seeds produced from one spike). Seedlings establish on water-logged soils, but not areas with wide water level fluctuations	November to March, though variable (see Mitchell and Rogers' 1985)	All Australian states except N.T. and the north-west. New Guinea, S-E Asia, New Zealand	Aston (1973), Sainty and Jacobs (1981), Finlayson et al. (1983)
Phragmites australis	B.1 Perennial	Conspicuous blade encircling stem	Vertical rhizomes bear aerial shoots, and horizontal ones are regenerating agent and main food store. Stems many-noded	Spreads mainly vegetatively (rhizome dispersal). Damaged plants regrow easily from old stems or rhizomes. Wind pollinated, abundant glumes. Germination in narrow range of habitats	January to April	Cosmopolitan	Aston (1973)
Isotoma fluviatilis	B.1 Perennial Paludal or aquatic	Elliptical to lanceolate	Creeping stems and shallowly rooted	Seeding (and fragmentation)	Summer	Vic., Tas.	Curtis (1963)
Gratiola nana	B.1 Perennial Paludal or aquatic	Thick, obovate to oblong	Creeping stems, rooted at the nodes	Seeding (and fragmentation)	Summer	Vic., Tas., New Zealand	Curtis (1967)
Centipeda minima	B.1 Annual (though behaved perennially in this survey) Paludal or aquatic	Olanceolate	Stems prostrate and rooting at the base	Numerous flower heads (composite)	Summer	Temperate Australia, New Zealand, E. Asia	Curtis (1963)
Scirpus nodosus	B.1 Perennial	Terete. Basal leaves reduced to sheaths	Rhizomatous	Cluster of numerous sessile spikelets	Throughout summer (own observations)	All Australian states and temperate parts of southern hemisphere	Willis (1970)
Nymphoides exigua	B.11 Perennial (own observations)	Obovate to orbiculate. Very delicate	Stout rootstock. Runners which root at the nodes	Fragmentation and seed production	Exact timing unknown. Specimens observed in this survey were infertile	Endemic to Tasmania	Curtis (1967)
Ranunculus rivularis	B.11 to B.111 Perennial Paludal or aquatic	Palmately divided	Stoloniferous	Fragmentation and seed production	September to March	N.S.W., Vic., S.A., Tas., New Zealand	Sainty and Jacobs (1981), Aston (1977)
Gratiola latifolia	B.1 Perennial	Broadly ovate, sessile	Fleshy stems, rooting at lower nodes	Seeding (and fragmentation)	Summer	Temperate Australia	Curtis (1967)
Nitella spp.	B.111 Alga	Whorled branches borne by a central axis	none	Fragmentation and production of oospores	none	Species of Nitella are found throughout Australia	Aston (1973), Sainty and Jacobs (1981)

Table 9 (continued)

	Lifeform (after Hutchinson 1975)	Leaf shape	Root system	Dispersal mechanisms and adaptations	Time of flowering and fruiting	Geographical range	References
Potamogeton perfoliatus	B.111 Perennial	Cordate and stem-clasping	Rhizomatous with long trailing stems	Vegetatively and by seed. Grows vigorously	Throughout summer	Qld.,Vic, N.S.W., Tas.	Sainty and Jacobs (1981)
Juncus kraussii	B.1 Perennial	Terete	Rhizomatous (horizontal) and densely clumped	Capsule with loose testa	Throughout spring and summer (own observations)	All Australian states, South Africa, New Zealand	Moore and Edgar (1970), Jessop and Toelken (1986),Jacobs and Pickard (1981)
Juncus articulatus	B.1 Perennial	Terete, septate leaves	Densely rhizomatous and creeping	Inflorescence seeds	Variable; spring to summer	Throughout Australia (except N.T.), Europe, Asia. (introduced)	Willis (1970), Sainty and Jacobs (1981)
Baumea arthrophylla	B.1 Perennial	Terete	Rhizomatous	Numerous spikelets producing seeds	Variable, but new inflorescence in November (own observations)	N.S.W., Qld., Vic., Tas.,S.A., W.A., New Zealand	Moore and Edgar (1970) Jessop and Toelken (1986), Jacobs and Pickard (1981)
Eleocharis sphacelata	B.1 Perennial	Leafless	Woody rhizome and deeply rooted	Many flowered spikelet. Produces abundant seed	Flowers November to April. Fruits December to April	Qld.,N.S.W.,S.A., Tas, New Guinea, New Zealand	Sainty and Jacobs (1981), Aston (1973)
Eleocharis acuta	B.1 Perennial	Leafless	Slender rhizome	Many flowered spikelet. Produces abundant seed	Flowers November to April. Fruits December to April	N.S.W., Qld., Vic., Tas., S.A., W.A., New Zealand	Sainty and Jacobs (1981), Willis (1970)
Scirpus fluitans	B.111 Perennial	Fine, thin and linear	Roots shallow. Stems rooting from the nodes	Vegetative. Produces nuts	October to April	All Australian states except N.T.. Africa, W and S Europe, S-E Asia, New Zealand	Aston (1973), Sainty and Jacobs (1981)
Lilaeopsis brownii	B.111 Perennial Paludal or aquatic	Cylindrical, hollow with transverse septa	Slender rhizomes, rooting at nodes. Shallowly rooted	Vegetatively or by seed	Summer	Endemic to Tasmania	Curtis (1963)
Triglochin procera	B.11 (but often B.1). Morphological form D found in this survey (after Robb and Ladiges 1981). Perennial	Strap-like and fleshy, often erect. (specimens observed in this survey had floating leaves)	Thick rhizome, bearing roots which end in tubers	Ripe fruits (carpels) germinate easily in shallow freshwater. Small plants survive winter	September to May	All Australian states	Sainty and Jacobs (1981), Aston (1973)
Villarsia reniformis	B.11 Perennial	Long petioles, and leaves as broad as long. Thick textured	Stoloniferous, and producing roots and shoots at the nodes	Vegetatively or by seed	October to March	Vic., Tas., S.A., N.S.W.	Sainty and Jacobs (1981), Aston (1973)

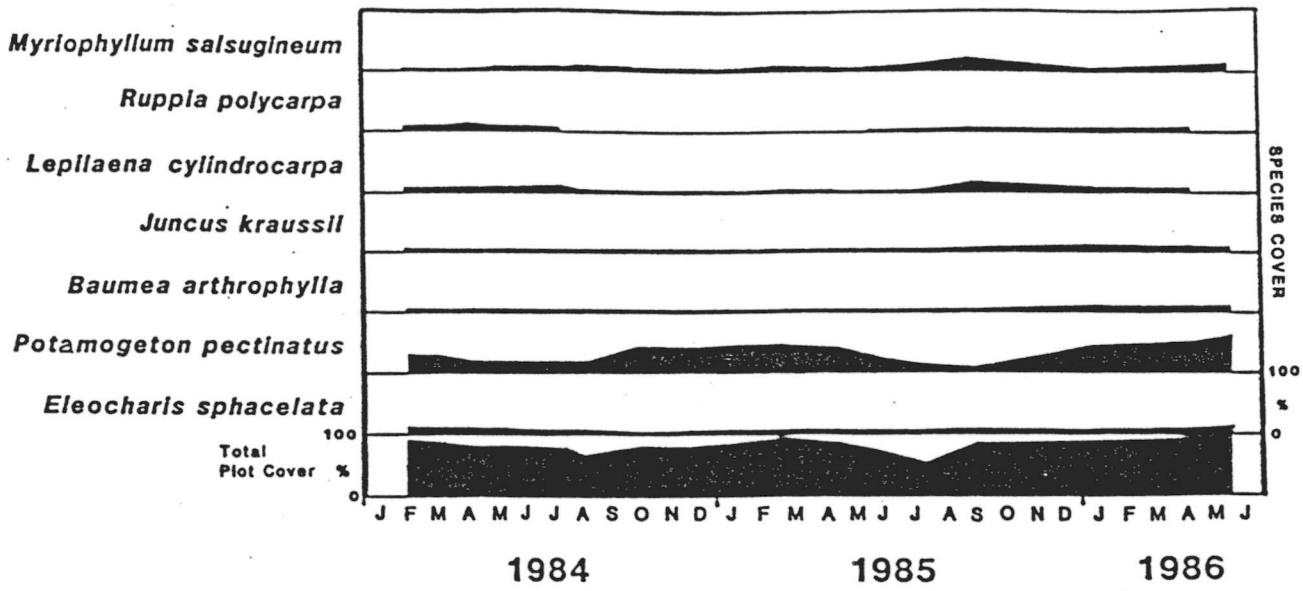
Table 9 (continued)

suitable to a disturbance environment in a stream (they are opportuistic or r-selected, MacArthur and Wilson 1967) e.g. tubers and rhizomes to ensure propagation after removal or die-back of vegetative parts, or leaf shape and flexibility to ensure residence in a fast flowing environment. Fragmentation and profuse rooting at the nodes enables propagation if suitable vegetative parts are washed away and deposited in a favourable environment. Seed production may be high if none of the above adaptations are present e.g. Typha orientalis, Phragmites australis and the emergent monocotyledons. Seeds may remain dormant during drought conditions, and germinate when river levels are high. It is true to say that the obligate aquatics have more adaptive mechanisms than the marginal, herbfield or fringing emergent species e.g. Centipeda minima, though whether these advantages are in terms of mechanisms to ensure residency, or in terms of mechanisms to ensure propagation is variable. All species observed are perennial.

3.4.2 Species cover, richness, diversity, beta turnover and evenness in space and time

The relative composition (% cover) of the species sampled in each plot over time is displayed in figures 52 to 65 and listed in Appendix 4. Figures 52 to 65 also display richness, diversity, evenness and turnover for each plot over time. Figure 66 graphs mean cover (%), richness (S), diversity (N_2), evenness (J') and mean cumulative beta turnover against time, and table 10 lists F-values for the three-way ANOVAs on community variables.

Figures 52 to 65 display considerable variation in percentage cover of individual species and total plot cover. Mean plot cover ranges from 28.86% in August 1984 to 51.36% in January 1985. Total plot cover differs among sites ($p < 0.001$), between seasons ($p < 0.001$) and between discharge ($p < 0.01$) (table 10). Mean plot cover is higher in summer than winter except plot 12 where the mean is slightly higher in winter, and is highest for plots at the



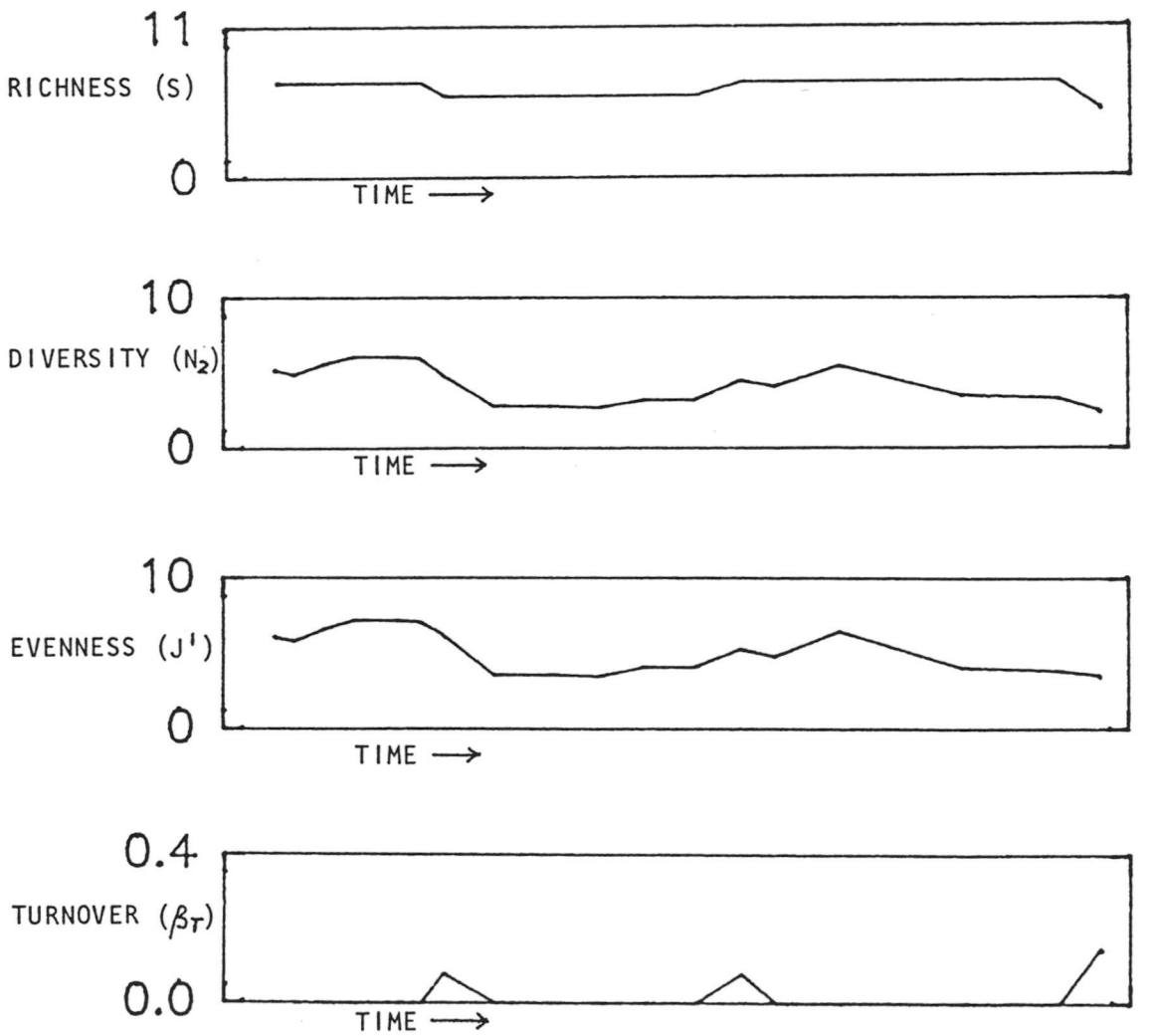


Fig. 52. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 1 from February 1984 to June 1986

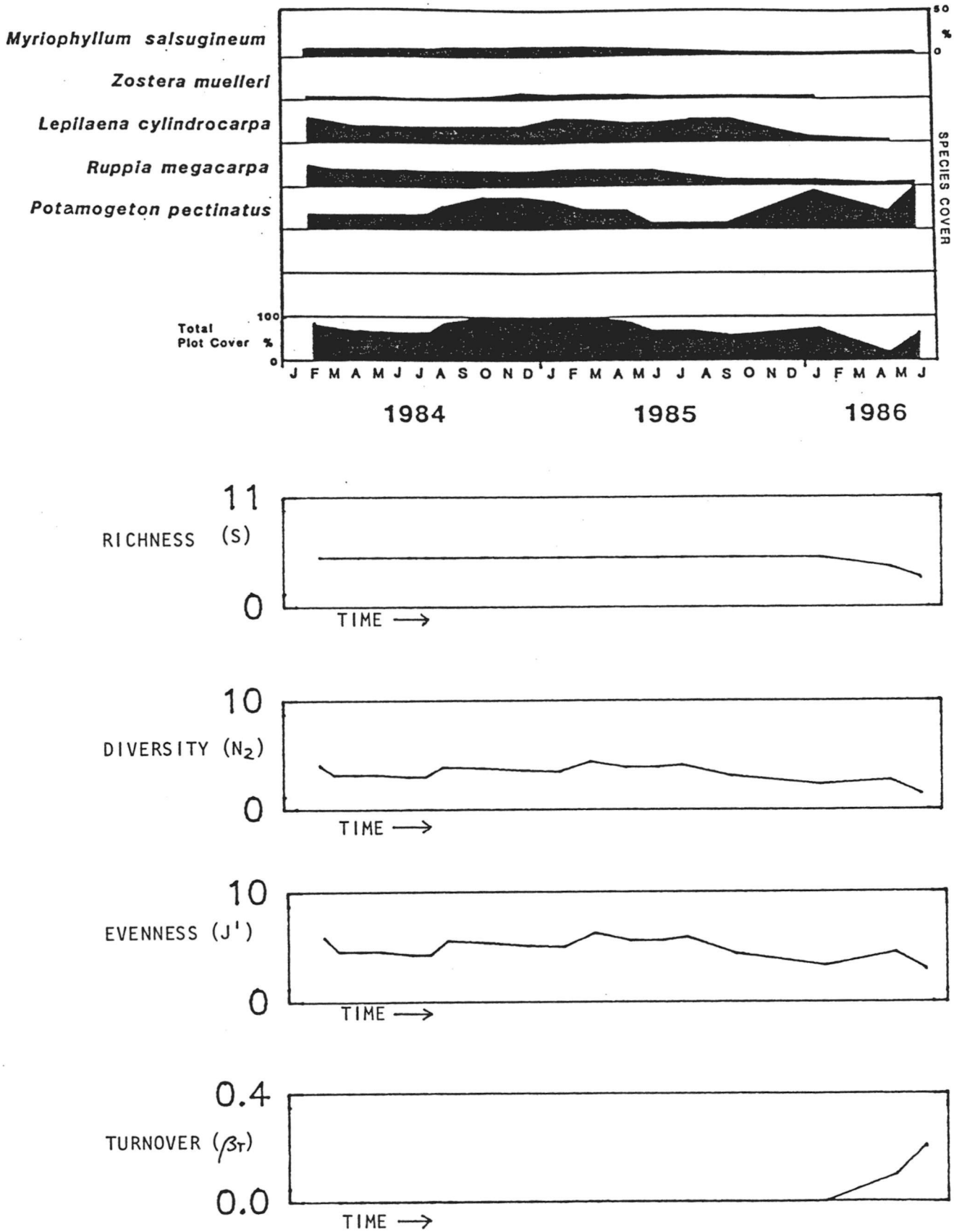


Fig. 53. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 2 from February 1984 to June 1986

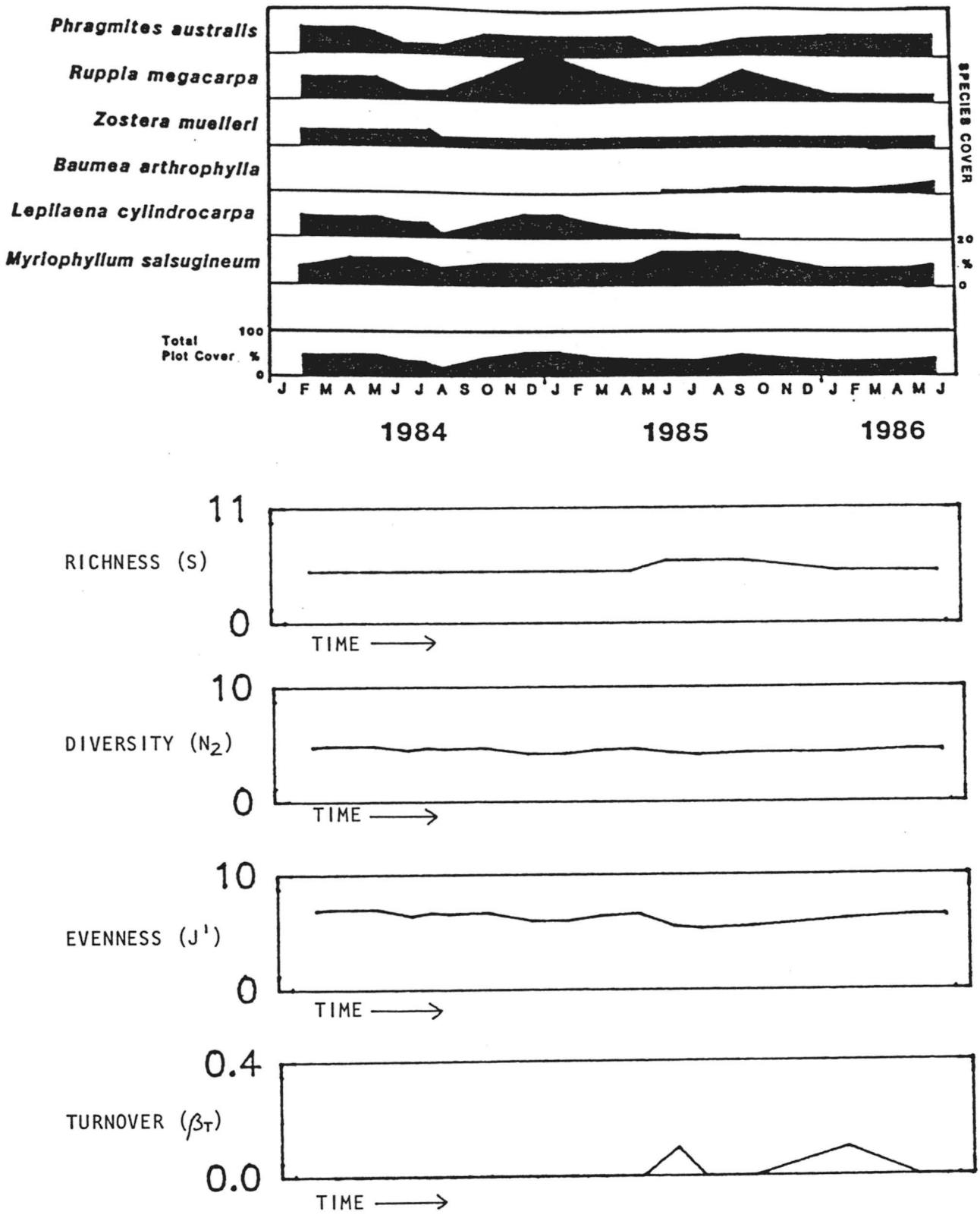


Fig. 54. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 3 from February 1984 to June 1986

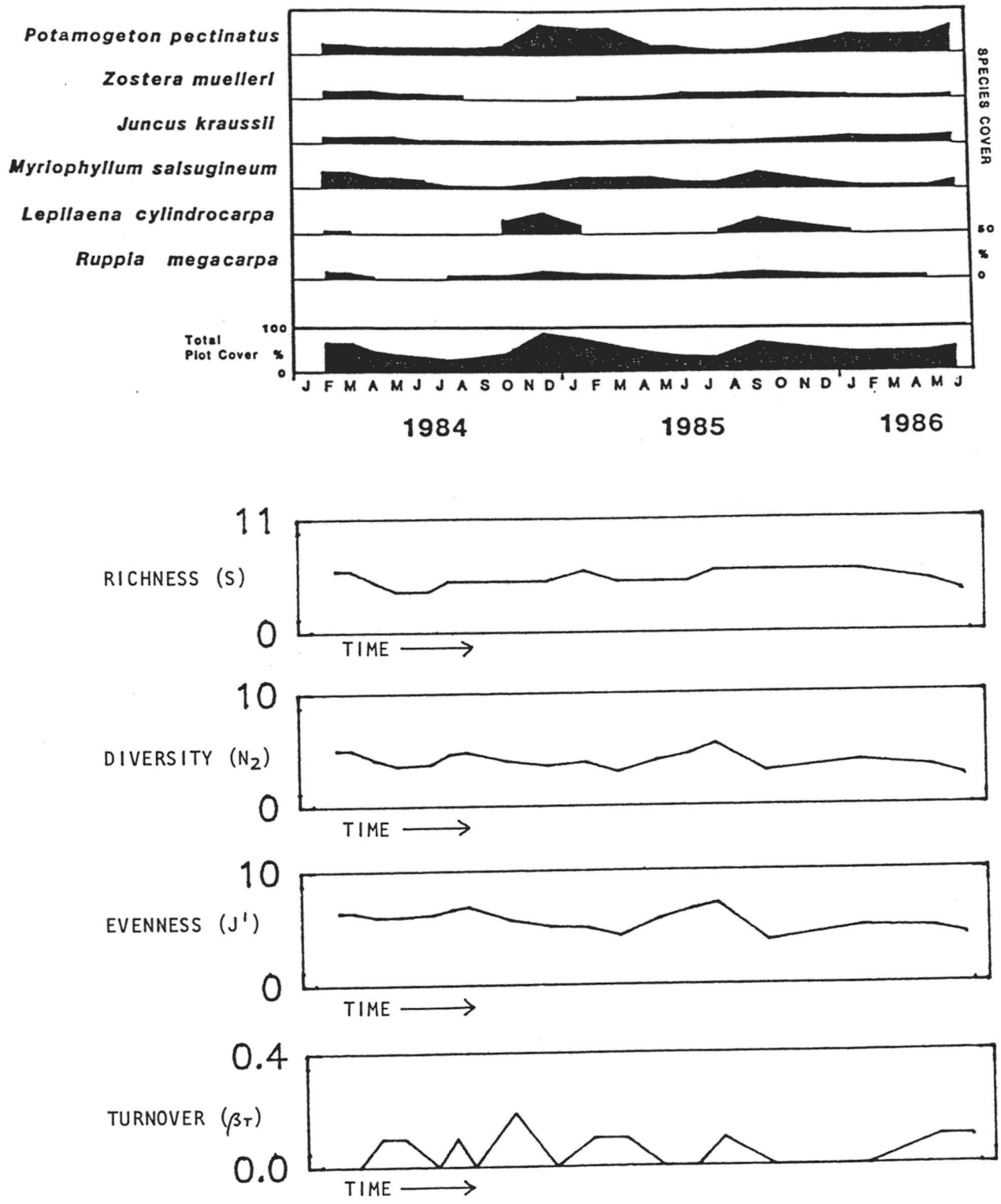


Fig. 55. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 4 from February 1984 to June 1986

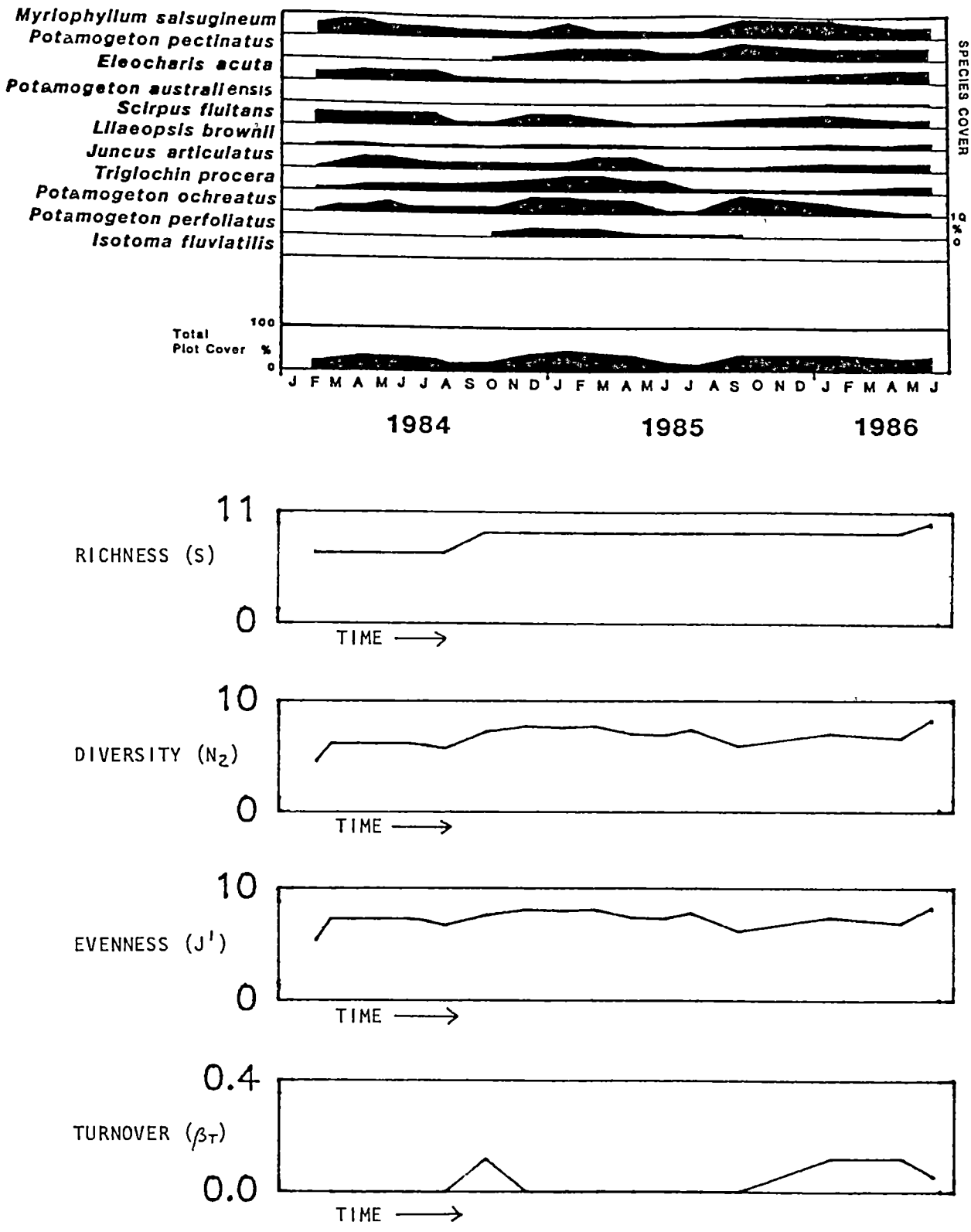


Fig. 56. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover ($ß_T$) of the aquatic flora sampled at plot 5 from February 1984 to June 1986

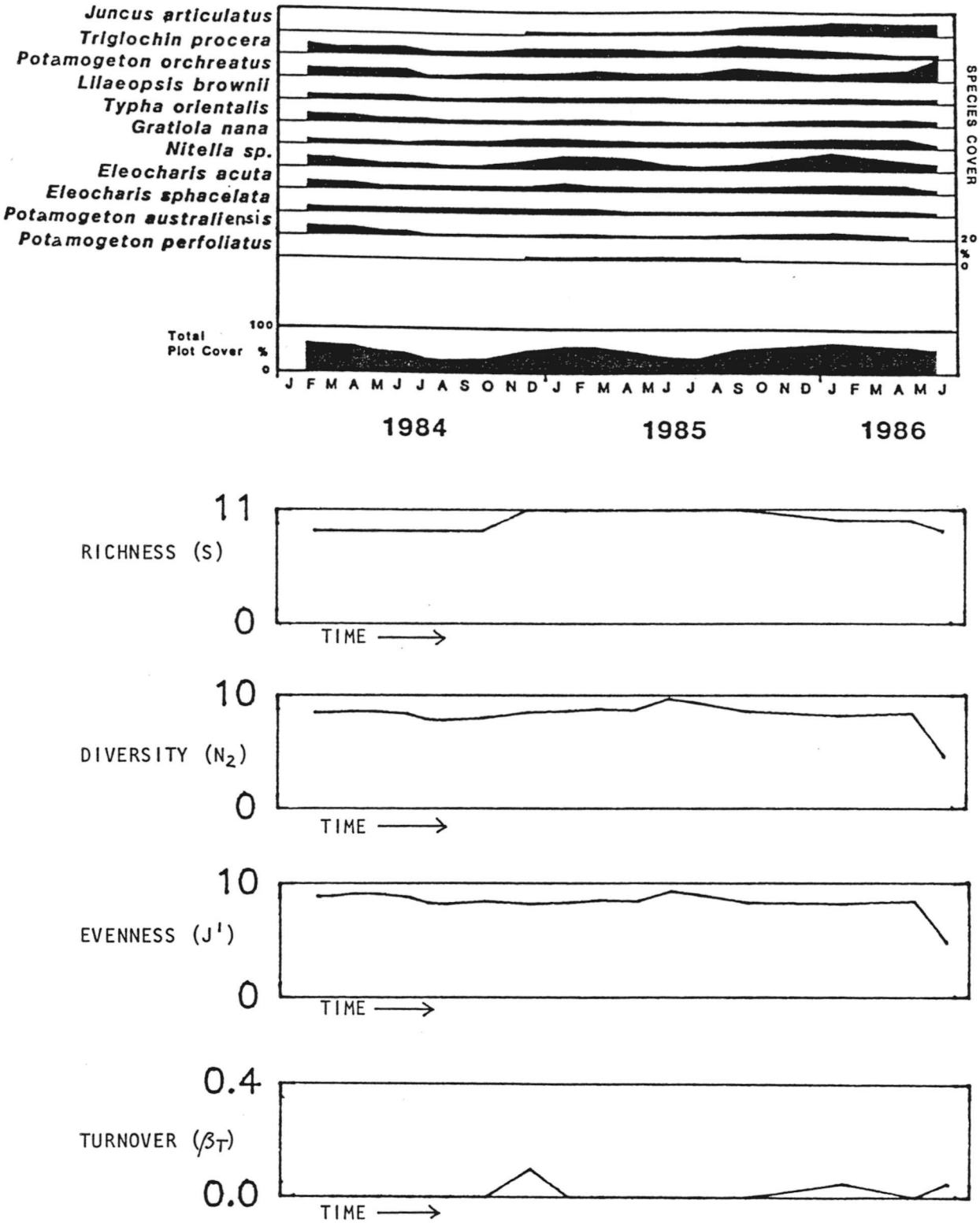


Fig. 57. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover ($ß_T$) of the aquatic flora sampled at plot 6 from February 1984 to June 1986

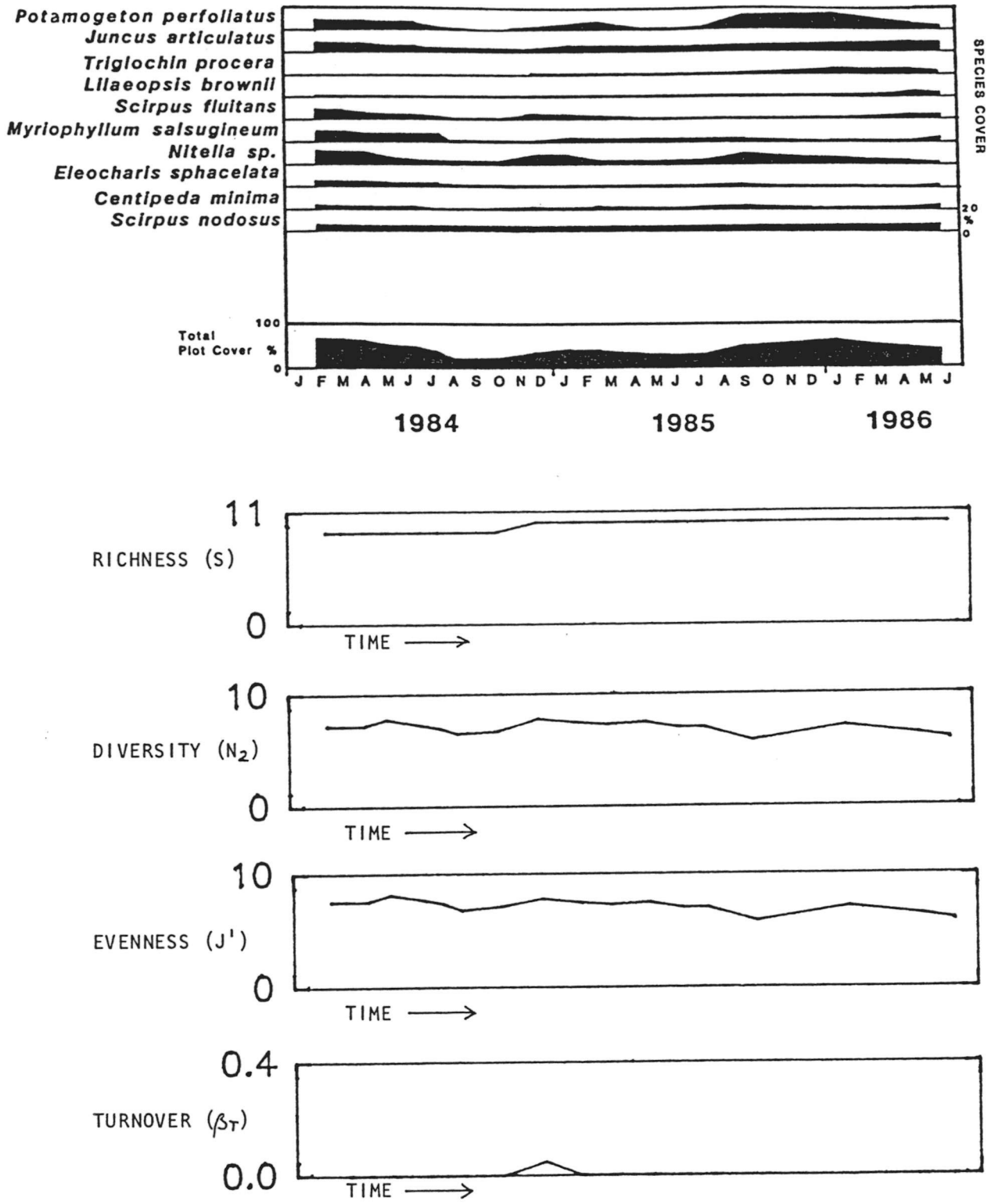


Fig. 58. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 7 from February 1984 to June 1986

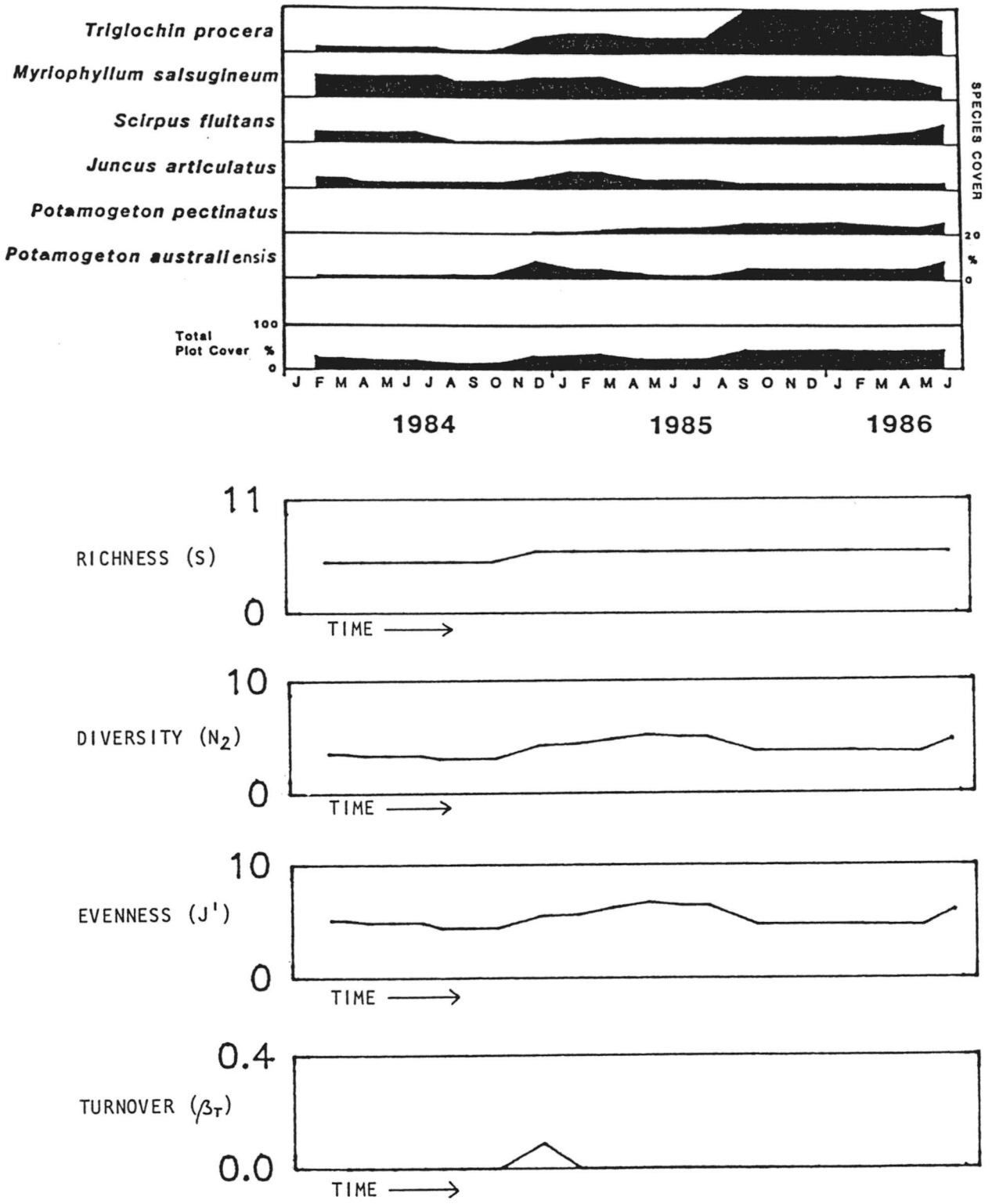


Fig. 59. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 8 from February 1984 to June 1986

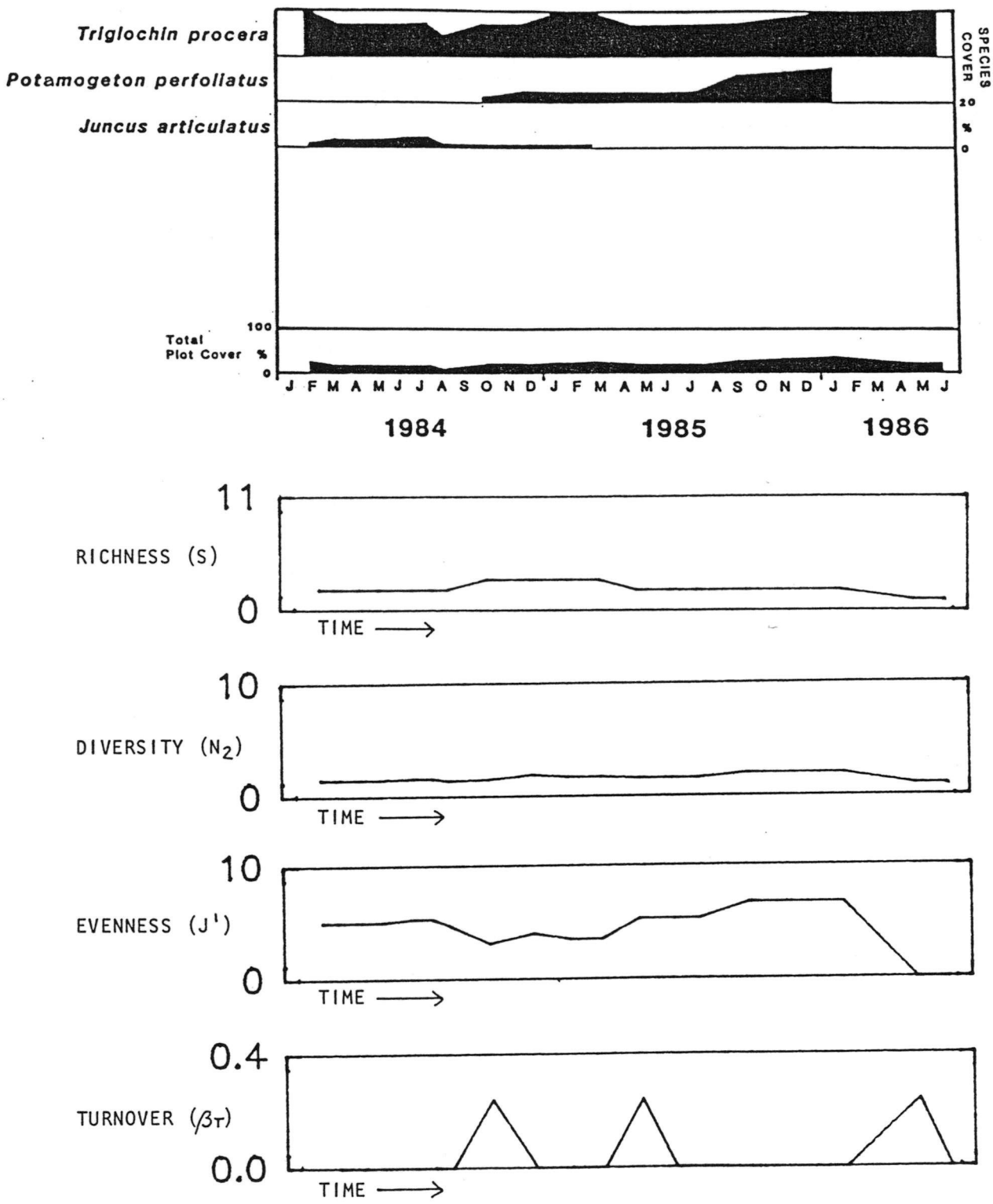


Fig. 60. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 9 from February 1984 to June 1986

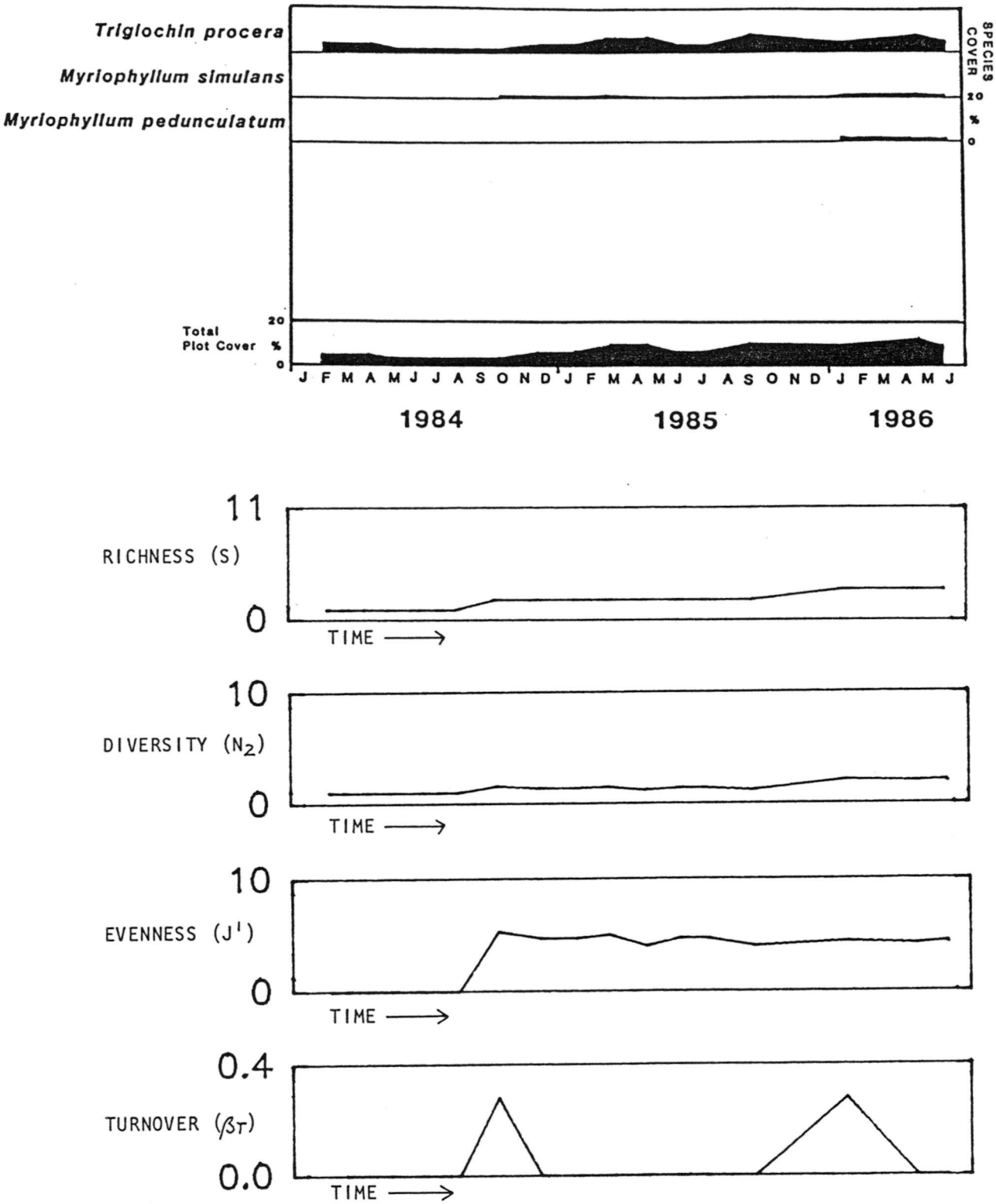


Fig. 61. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 10 from February 1984 to June 1986

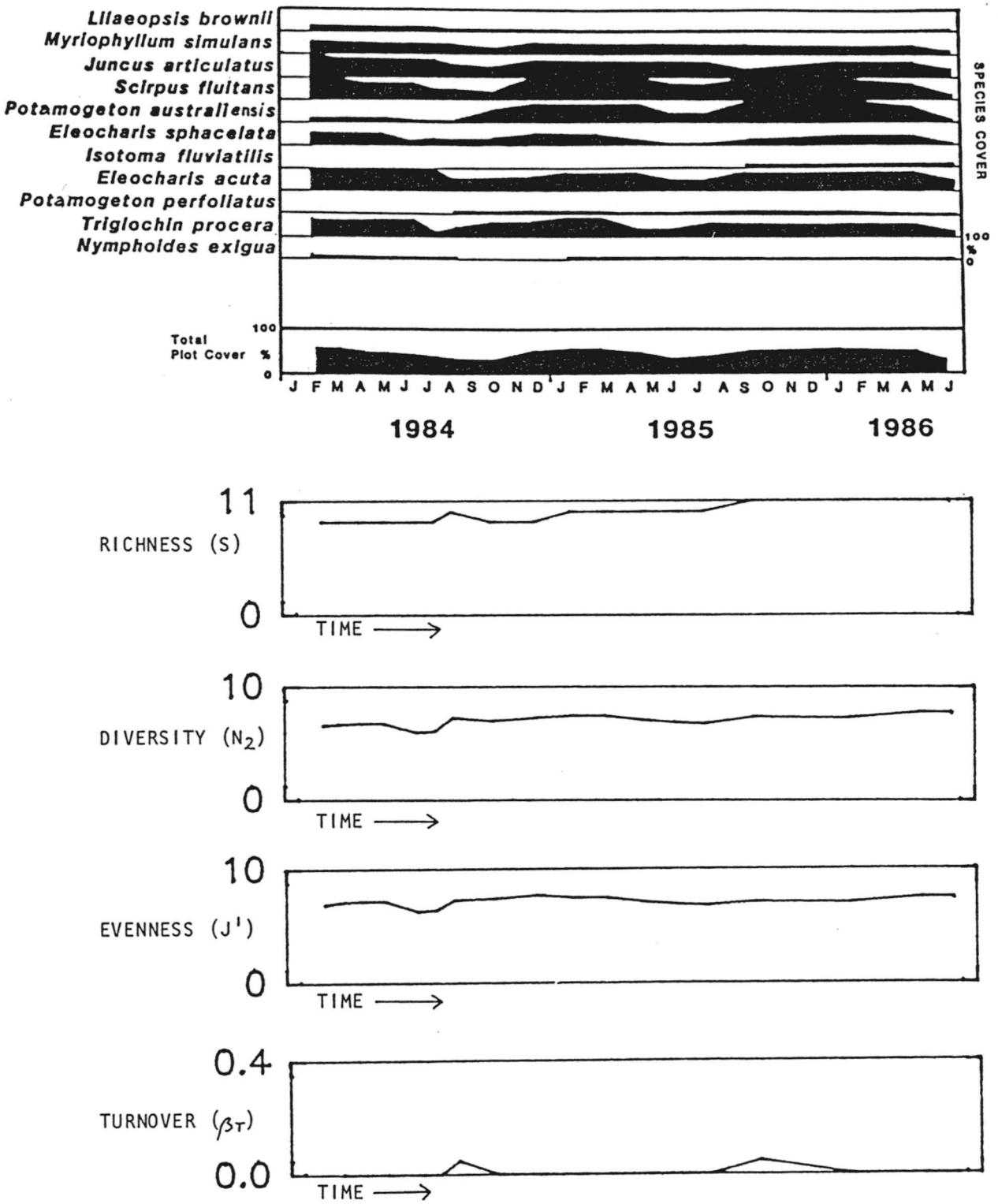


Fig. 62. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 11 from February 1984 to June 1986

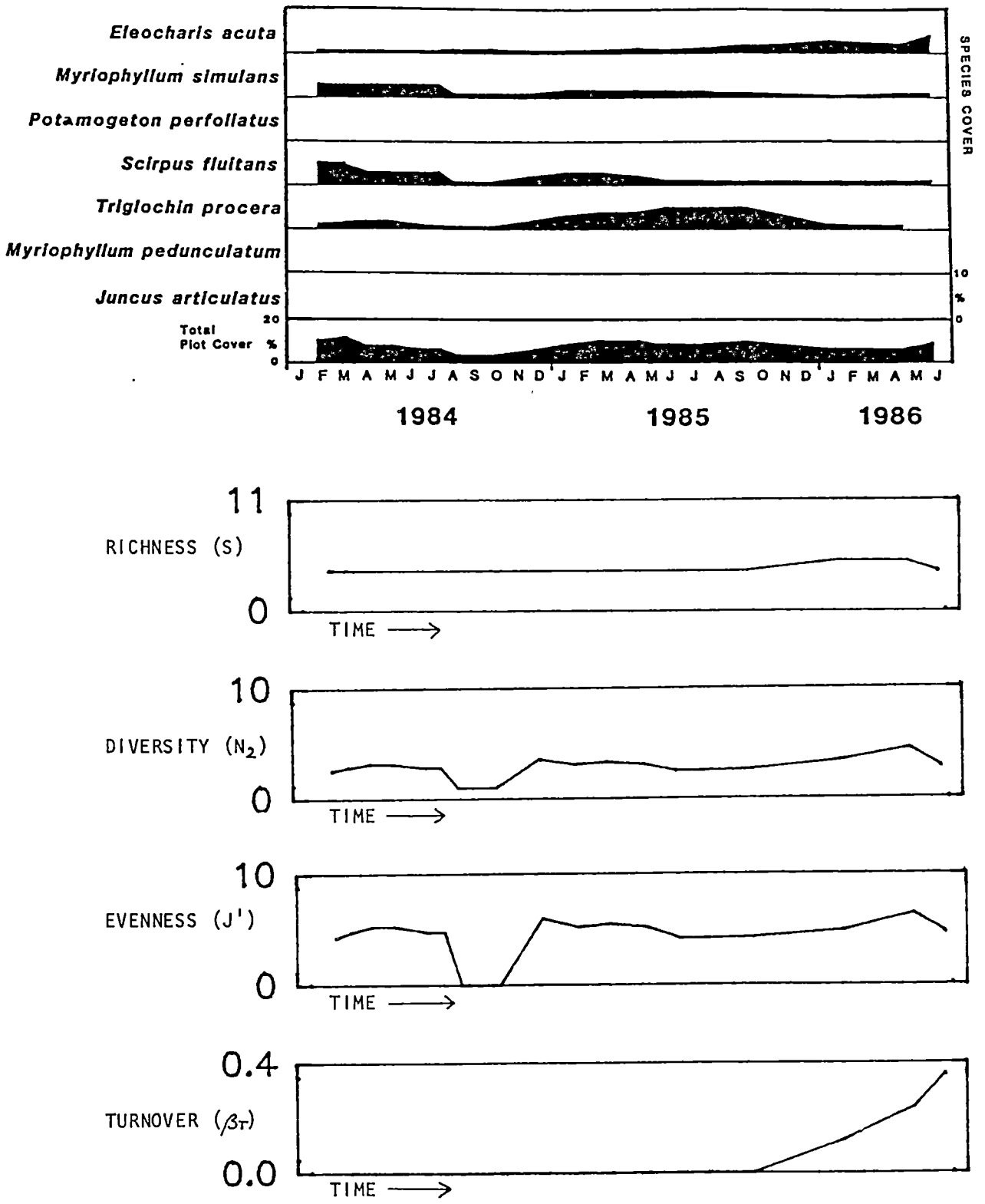


Fig. 63. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 12 from February 1984 to June 1986

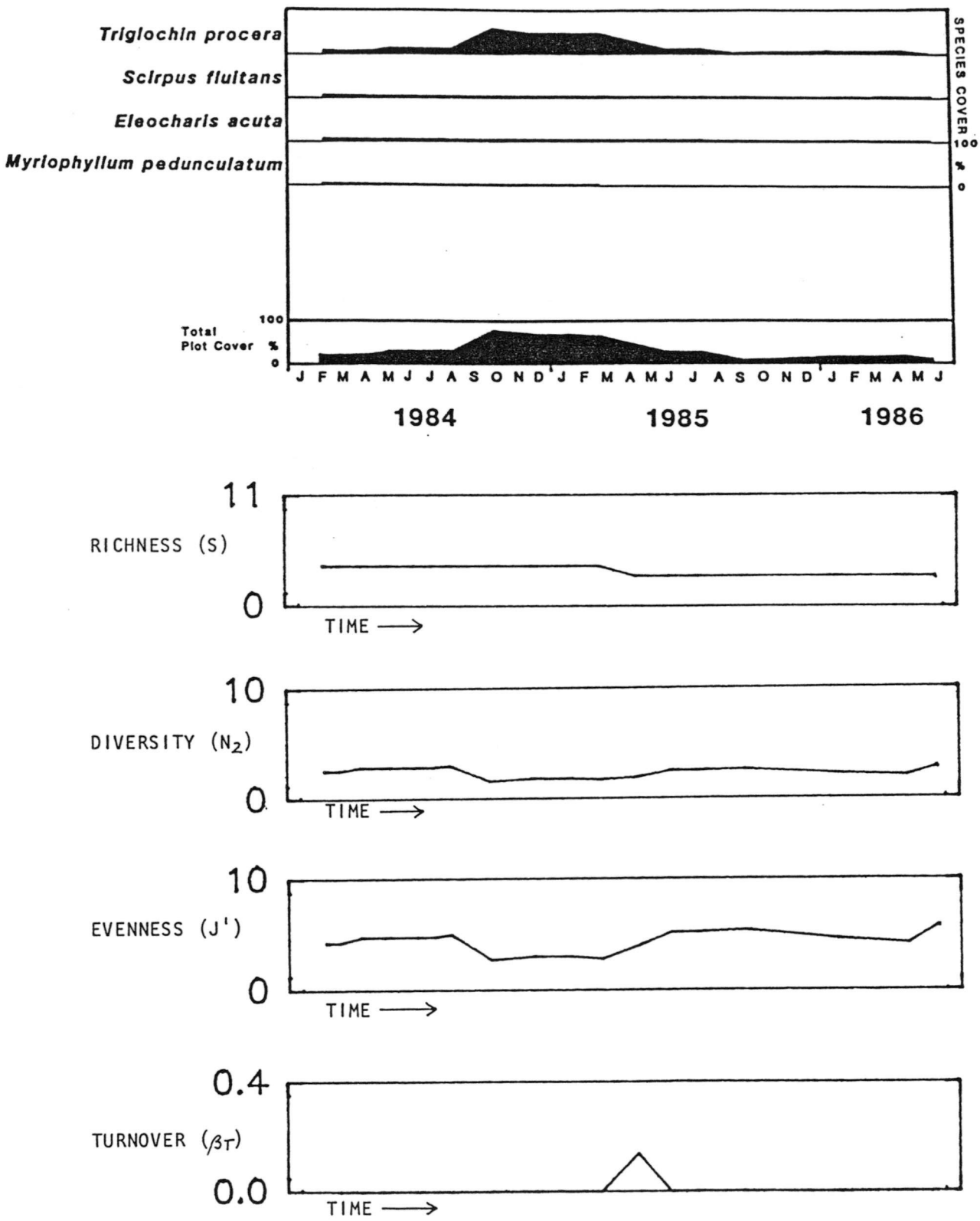


Fig. 64. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 13 from February 1984 to June 1986

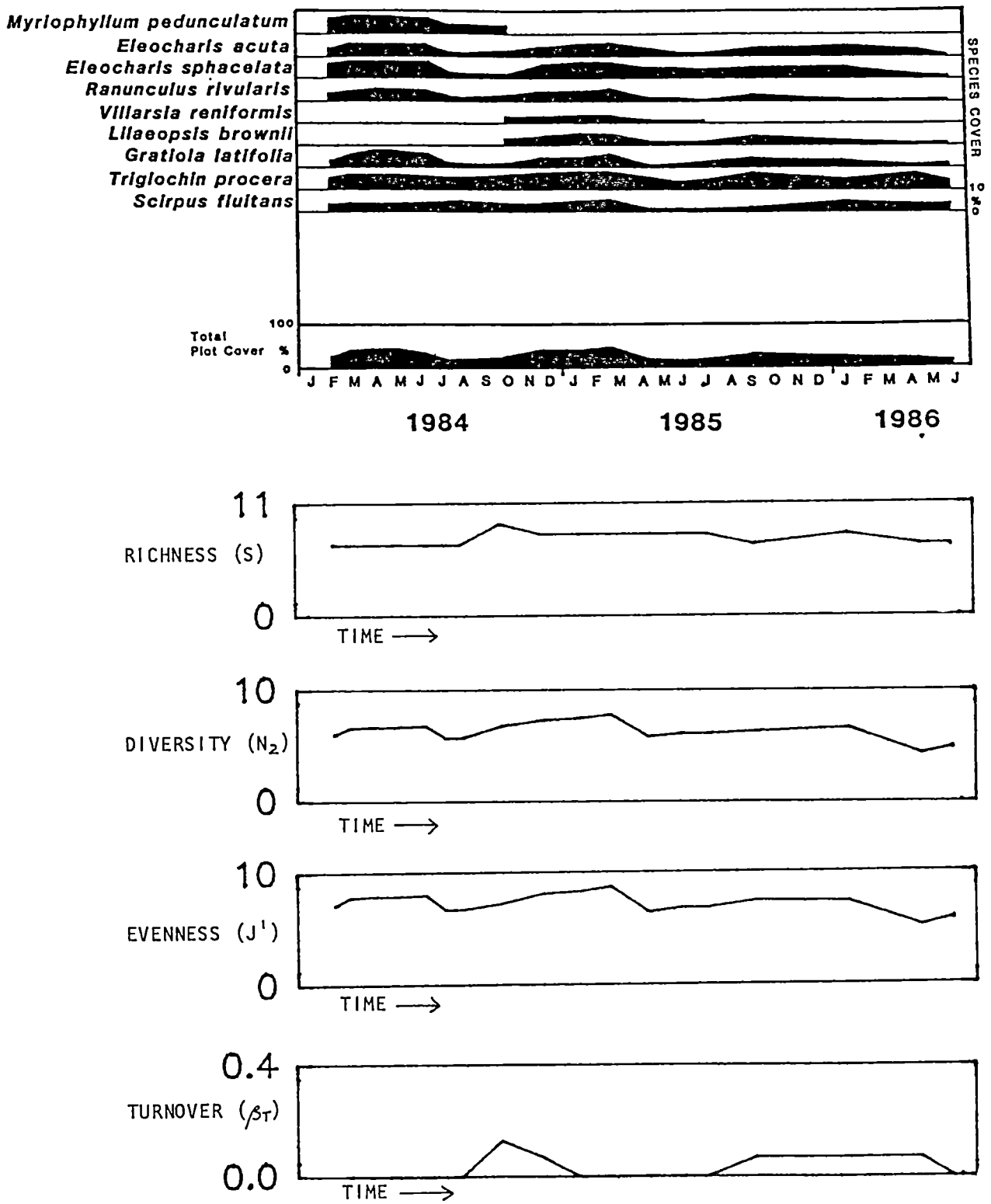


Fig. 65. Relative composition (% cover), richness (S), diversity (N_2), evenness (J') and turnover (β_T) of the aquatic flora sampled at plot 14 from February 1984 to June 1986

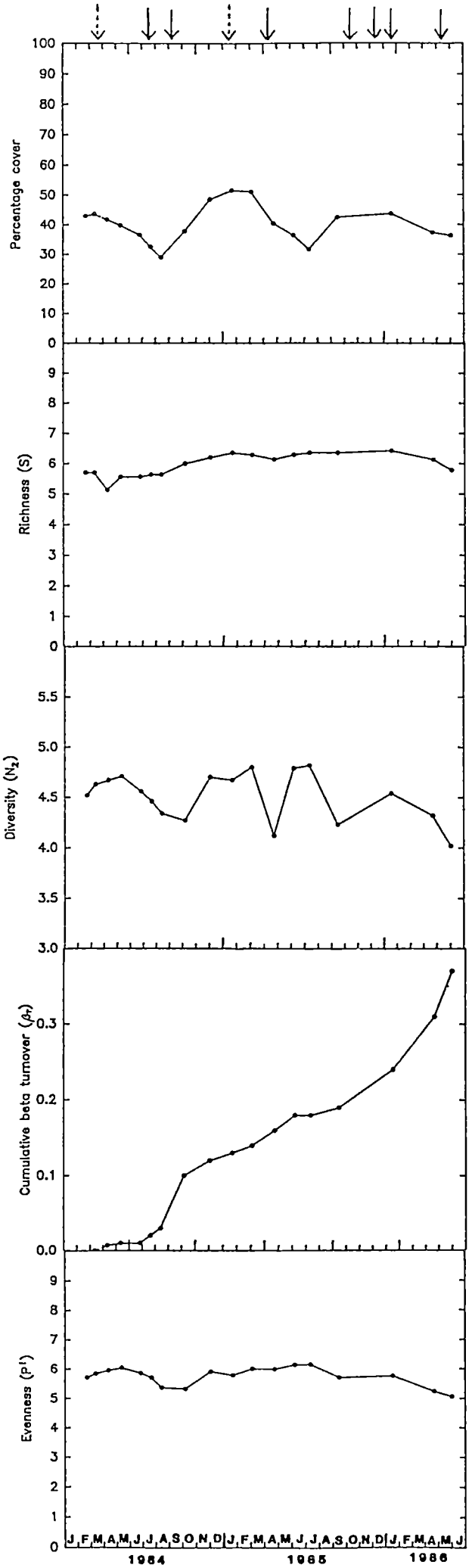


Fig. 66. Mean percentage cover, richness, diversity, evenness, and cumulative beta turnover plotted against time

The arrows at the top of the graphs indicate high (⟶), and low (----⟶) discharges

	Source of variation					
Variable	Site N = 14	Season N = 2	Hydrology N = 3	Site x Season	Site x Hydrology	Season x Hydrology
Log_{10} Cover	108.57 p<0.001	19.32 p<0.001	4.99 p<0.01	1.06 N.S.	1.11 N.S.	3.92 p<0.05
Richness (S)	347.05 p<0.001	12.10 p<0.001	6.36 p<0.01	1.24 N.S.	1.80 p<0.05	0.64 N.S.
Diversity (N_2)	180.29 p<0.001	0.17 N.S.	2.77 p<0.10	2.69 p<0.01	1.61 p<0.05	0.36 N.S.
Beta turnover (β_t)	1.76 p<0.10	2.39 N.S.	14.27 p<0.001	1.67 p<0.10	1.35 N.S.	1.19 N.S.
Evenness (J')	34.62 p<0.001	0.04 N.S.	2.49 p<0.10	2.48 p<0.01	1.88 p<0.01	0.06 N.S.

Table 10. F-values and their associated levels of significance for the three-way ANOVAs on community variables (N.S. = not significant)

mouth of the Swan River and lowest for plots in the upper catchments. Cover is generally higher during low discharge with the exception of plot 1 which has a higher cover during high flow, and plots 8, 9, 12 and 13 which have higher cover during steady flow. These inconsistencies for discharge and season probably explain the significant season x discharge interaction term ($p < 0.05$).

Species richness (S) also differs among sites ($p < 0.001$), between seasons ($p < 0.001$) and between discharge ($p < 0.01$). Species richness is higher in summer than winter with the exception of plots 1, 3 and 11, and seven plots increased in richness after high discharges. Mean species richness varies from 5.14 in April 1984 to 6.36 in January, July and September 1985 (fig 66). Mean species richness per plot varies from 1.78 for plot 10 to 9.89 for plot 6. The site x discharge interaction is significant ($p < 0.05$) indicating that these two variables jointly affect the dependent variable.

Values of mean diversity (N_2) range from 4.12 in April 1985 to 4.82 in July 1985 (fig 66), but these average figures even out the variability of diversity over time (see individual graphs of diversity in figures 52 to 65). Thus mean diversity per plot varies from 1.35 for plot 10 to 8.33 for plot 6. Species diversity differs among sites ($p < 0.001$) and between discharge ($p < 0.10$) but does not differ between seasons. Ten plots increased in diversity after a low or steady period of flow. However, increases in diversity after a flood (i.e. plots 5, 8, 10, 11) were larger than those after low flow events with a mean (and range) of 0.53 (0.34 to 0.79) and 0.38 (0.2 to 0.61) respectively. The site x season and site x hydrology interactions are both significant ($p < 0.01$ and $p < 0.05$ respectively). Thus part of the variation in species diversity is related to the joint effects of both sets of variables as a consequence of their intercorrelations. The season x hydrology interaction is not significant.

Evenness (J') differed among sites ($p < 0.001$) and between discharge ($p < 0.10$), but not significantly between season. Evenness displayed similar interactions to diversity ($p < 0.10$ and $p < 0.01$ for site x season and site x discharge respectively). There is a tendency towards higher evenness after a steady or low flow event with the exception of plots 8, 10, 11 and 13. Values of mean evenness range from 5.06 in June 1986 to 6.16 in September 1985 (fig 66), and mean plot values range from 2.78 for plot 10 to 8.40 for plot 6.

N_2 is a measure of species polydominance with the maximum attainable value being equal to the species richness at the particular recording time. For example, in plot 1, N_2 decreases after the July 1984 flood to 2.8 (S ranges from 5 to 7) (see fig 52) and Potamogeton pectinatus becomes the dominant species. By contrast, in plot 6, N_2 is greater than 7.8 throughout the study period (with S ranging from 9 to 11), but drops to 4.7 in June 1986 with Potamogeton ochreatus dominance (fig 57). N_2 must therefore be examined in the context of S to obtain an assessment of species polydominance, and hence the usefulness of an evenness measure (J'). Thus J' increases when there is high species polydominance, and decreaes with species dominance. The J' curves in figures 52 to 65 follow the same pattern as those of diversity, with the exception of plots 9 and 10. Plot 9 (fig 60) displays a variable J' curve, but a smooth trend in diversity. In February 1984 Triglochin procera is the dominant species and Juncus articulatus is also present. Potamogeton perfoliatus is recruited in October 1984 and evenness decreases. In September 1985 evenness increases to 6.7 due to the polydominance of Triglochin procera and Potamogeton perfoliatus. Evenness equals zero in February 1984 for plot 10 (fig 61), reflecting the presence of one species only. An increase in evenness occurs with the gain of Myriophyllum simulans, and the curve levels out as the % cover of the three species changes. On the whole, the plots display relatively high species polydominance, though this does vary over time.

Beta turnover (β_T) varies significantly ($p < 0.001$) between discharge and less significantly among sites ($p < 0.10$) (table 10). There is no significant difference between seasons. The site x season interaction jointly affects the dependent variable ($p < 0.10$). Species turnover occurs after floods or high discharge events for ten plots and after low flow events for three plots. Turnover occurred during steady flow for plot 4 (see fig 52 to 65). Mean cumulative beta turnover ranges from 0.007 at the start of the record to 0.37 in June 1986 (fig 66). Mean turnover per plot varies from 0.01 for six plots to 0.06 for plot 4.

Beta turnover in plot 4 (fig 55) varies with the loss and gain of Lepilaena cylindrocarpa as well as Zostera muelleri and Ruppia megacarpa. Plot 7 (fig 58), which displays consistently high polydominance, has only one change in turnover of 0.05. Turnover for plots 9 and 10 (fig 60 and 61) is relatively high, but this is accentuated by the low species richness. The highest beta turnover is recorded in plot 12 (fig 63) after the summer 1986 floods recruited Myriophyllum pedunculatum and Juncus articulatus.

3.4.3 Classification and ordination

The results of the classification and ordination may be divided into:

a) classification to examine major groupings within the 14 plot x 18 time samples;
b) ordination to investigate major trends in the 14 plot x 18 time samples;
c) investigation of between-plot variability in ordination-space;
d) ordination to investigate within-plot variability over time.

The results of the 252 sample classification (using species cover data) were initially analysed for major groupings at the between-plot scale. The integrity of the plots was maintained at the 4-group division (fig 67), with a major

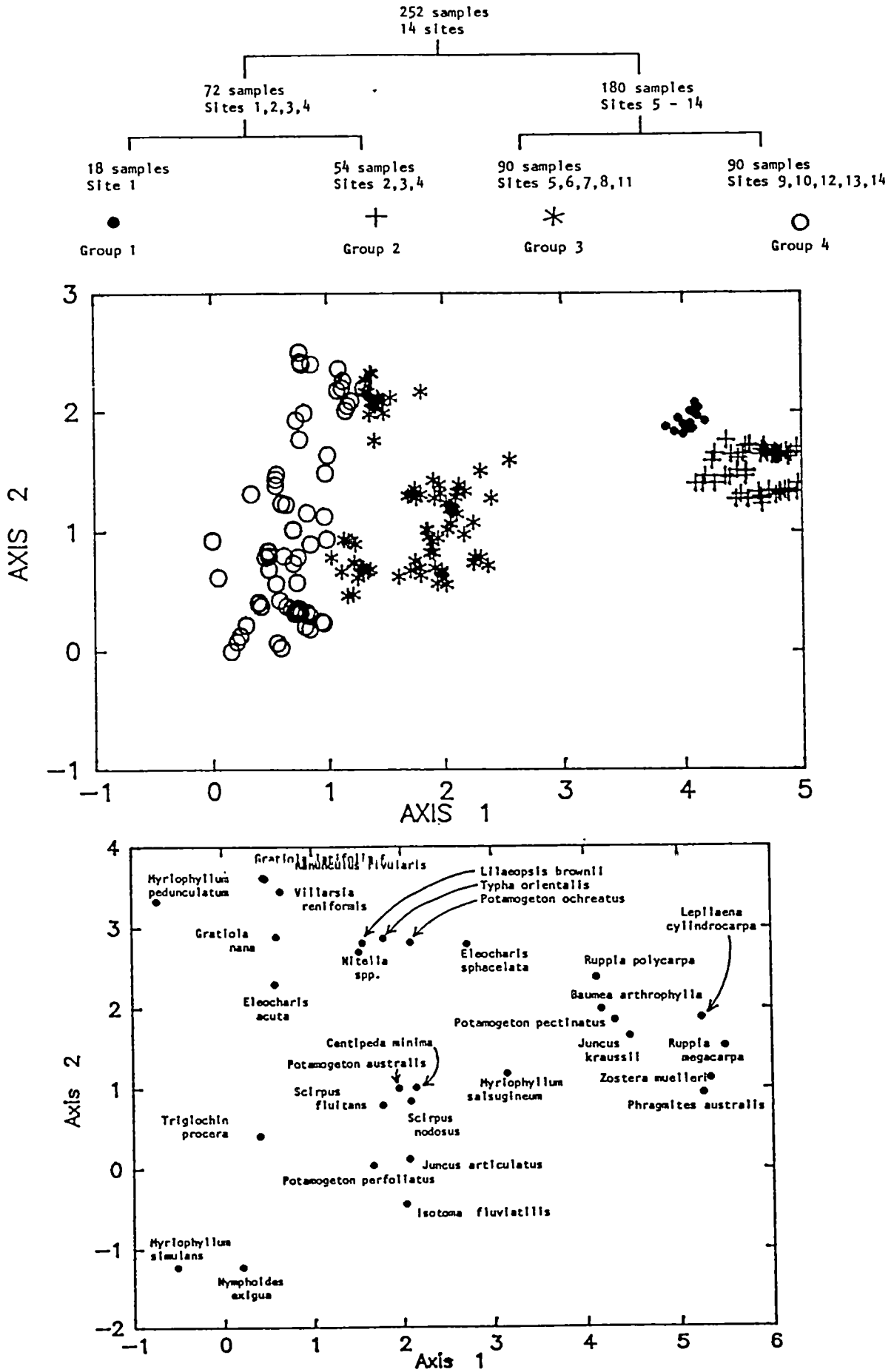


Fig. 67. Classification and ordination of the 252 sample x 30 species matrix. Cut levels 0, 5 and 10 are used for the classification. The groups derived from the classification are superimposed onto the ordination scores of axes 1 and 2. The species scores associated with the groupings are plotted below

division between samples in the brackish component of the Swan River (indicator species are Lepilaena cylindrocarpa and Myriophyllum salsugineum), and those in the freshwater component of the Swan and Apsley Rivers (indicator species are Triglochin procera and Scirpus fluitans). The brackish-water sites are subdivided into plot 1 (group 1) and plots 2, 3 and 4 (group 2). The indicator species responsible for group 1 (plot 1) is Eleocharis sphacelata, and Ruppia megacarpa is the indicator species for group 2. Ruppia polycarpa is found intermittently over time in plot 1 only, and species exclusive to the other plots are Phragmites australis, Ruppia megacarpa and Zostera muelleri.

The freshwater samples are subdivided into group 3 (plots 5, 6, 7, 8 and 11) and group 4 (plots 9, 10, 12, 13 and 14) (fig 67). Group 3 has Juncus articulatus, Lilaeopsis brownii and Potomogeton australiensis as indicator species and the plots are situated in the middle reaches of the Swan and Apsley Rivers. Group 4 has no indicator species, though Myriophyllum pedunculatum, Ranunculus rivularis, Villarsia reniformis and Gratiola latifolia are only found in this subdivision. These plots are either situated in the upper reaches of the rivers or on rocky/pebbly substrata.

The results of the ordination indicate that the major proportion of the variation is explained by axis 1 (eigenvalue = 0.855) and this is plotted against axis 2 (eigenvalue = 0.299) in figure 67. The groupings derived from the classification have been superimposed, and axis 1 clearly distinguishes the brackish from the freshwater samples, and samples from the midreaches (*) and upper reaches (O) of the rivers. Axis 2 reflects the gradient from periodically inundated sites (supporting marginal herbfield species e.g. Myriophyllum pedunculatum, Villarsia reniformis) to permanently inundated sites (supporting submerged hydrophytes e.g. Potamogeton perfoliatus, Triglochin procera, Scirpus fluitans). This pattern is reflected in the species ordination in figure 67.

Between-plot variability (the spatial pattern) was further investigated by examining distributions of individual plots in ordination-space on axes 1 and 2. Figure 68a displays the ordination scores for each plot in group 1 (plot 1) and group 2 (plots 2,3,4). The dendrogram derived from the TWINSPAN classification (below graph 68a) clarifies the ordination results, and highlights the distinctive nature of plot 1. Plot 3 is also relatively isolated in the classification, though the samples from this plot are closely related to plots 2 and 4 in ordination-space (clarified by the dendrogram). Potamogeton pectinatus does not grow in plot 3, and is the indicator species for plots 2 and 4. There appears to be low between-plot variability (i.e. differences in scores between plots) for plots 2 and 4, with no clear separation in ordination-space (fig 68a).

Between-plot variability for group 3 is shown in figure 68b. Samples from plot 6 are well separated and display high between-plot variability. Plot 6 is sited in an intermittent overflow channel on the midreaches of the Swan River, and species exclusive to this plot are Typha orientalis and Gratiola nana (see table 8). Plot 11 additionally demonstrates high between-plot variability, and is situated along the Apsley River upstream of the Coles Bay Road. The endemic aquatic angiosperm, Nymphoides exigua, is found only in plot 11. Plots 5,7 and 8 are situated along the Swan River at the Grange, and display less distinctive between-plot variability than plots 6 and 11.

Variability between plots in group 4 (fig 68c) is less distinctive than for plots in groups 1,2 and 3. Plots 9,12 and 13 have overlapping distributions in ordination-space. These three plots are situated at the Swan River causeway (pebbly substrate), downstream of the Apsley River weir (rock substrate) and near the Apsley River causeway (sand/gravel substrate) respectively. The aquatic plant communities in these plots are species-poor and are characterised by submerged hydrophytes e.g. Triglochin

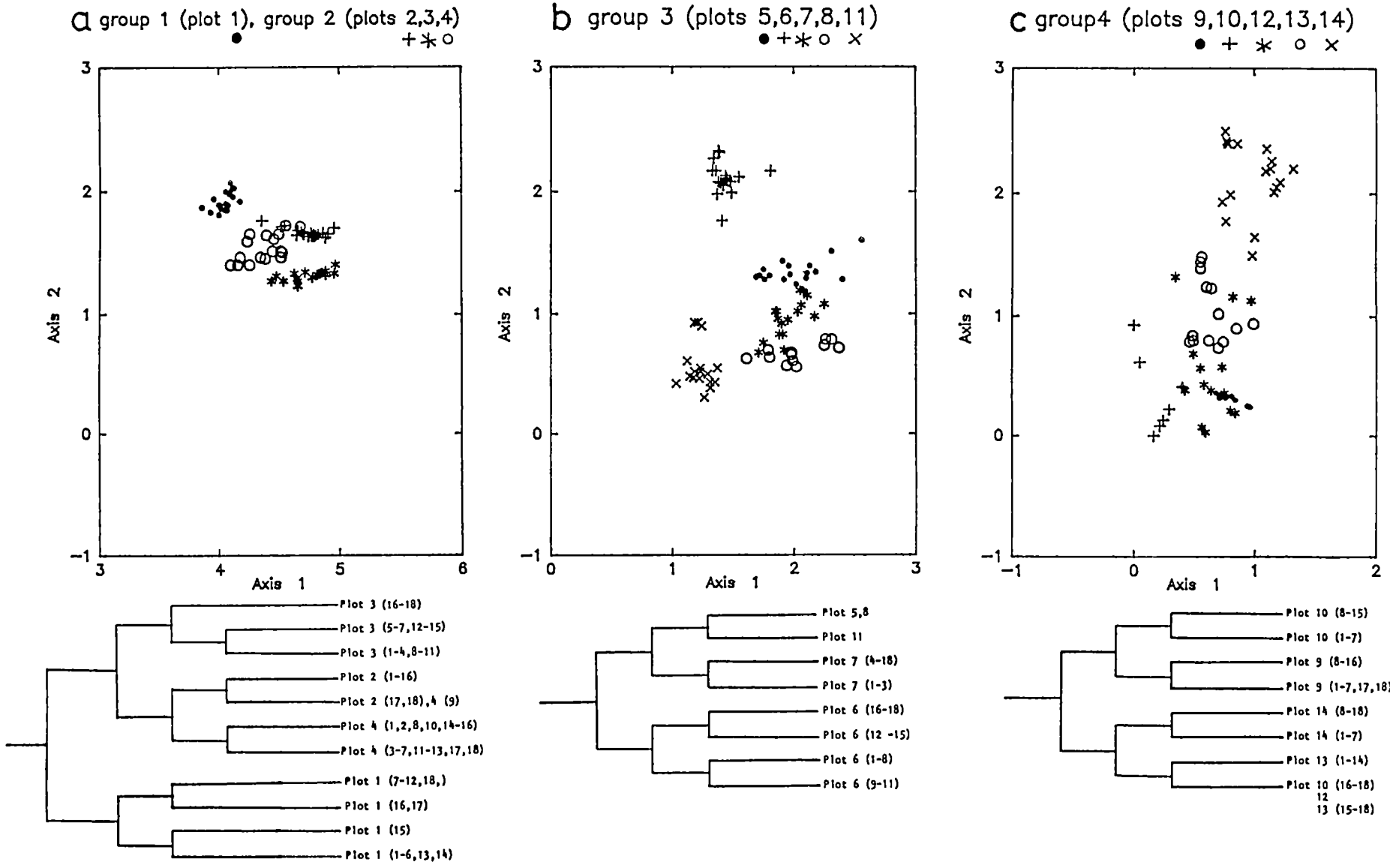


Fig. 68. Ordination of the 14 x 18 samples with plots superimposed: a) group 1 and group 2; b) group 3; c) group 4

procera, Myriophyllum simulans, Scirpus fluitans, a marginal herbfield species, Myriophyllum pedunculatum, and one species of emergent helophyte, Juncus articulatus. Plot 14 is situated on the floodplain of the Apsley River, by the causeway, and is intermittently flooded. It supports Villarsia reniformis, Gratiola latifolia and Ranunculus rivularis which are exclusive to this plot, as well as species such as Lilaeopsis brownii and Triglochin procera. Plot 10 has two species, Triglochin procera and Myriophyllum simulans, but acquires Myriophyllum pedunculatum in samples 16 to 18, thereby diminishing between-plot variability (see dendrogram). Plot 10 is situated in the rocky upper reaches of the Swan River.

The detailed dynamics occurring within individual plots were investigated by ordinating species cover data of each plot, plotting the time trajectories (figures 69-75) and by investigating the associated species ordination. The trajectories for plots 1 to 14 display some erratic behaviour, although some individual patterns appear evident. Samples 1 to 6 in plot 1 were obtained during the low to steady flow period from February to July 1984. A marked shift in ordination-space occurs during the August 1984 flood (sample 7), when there is a decrease in diversity (N_2) and Ruppia polycarpa is eliminated from the plot. Axis 1 represents a salinity gradient: during the February to July 1984 low flow period (samples 1 to 6), filterable residue was at its highest due to an increased precipitation-evaporation ratio and due to less freshwater reaching the mouth of the river (see section 3.2.3). Consequently, the salt-tolerant species Ruppia polycarpa competed favourably with Potamogeton pectinatus and Myriophyllum salsugineum. Ruppia reappears in June 1985, probably as a consequence of the autumn 1985 floods transporting rhizomes into the plot. After the autumn 1985 floods, the trend is towards Lepilaena cylindrocarpa and Myriophyllum salsugineum dominance. This pattern is again reversed after the floods in early 1986 (sample 16). The plot trajectories and associated species ordinations reflect

the species responses to the changing discharges and consequent changes in water chemistry.

Plot 2 displays some interesting trends. A major reversal of the trajectory occurrs at sample 9, during low summer flow in December 1984. The trend from sample 1 to 9 is towards Potamogeton pectinatus dominance, but this is reversed with the growth of Lepilaena cylindrocarpa in sample 10. Other major changes in the direction of the trajectory occur at sample 13 (winter floods of 1985) and sample 16 (1986 floods).

The trajectory trends between these displacements may be interpreted as seasonal changes. There is a seasonal pattern of aquatic plant growth in early summer and decomposition in late autumn, with interruptions from induced population fluctuations after high or low flow events. This pattern is evident for plots 3 and 4. Sample 7 (August 1984 flood) in plot 3 demarks a sharp break in the trajectory trend, while sample 9 (summer 1984 low) reverses this pattern. Convergence of the temporal sequence occurs at sample 13, after the June 1985 flood. Myriophyllum salsugineum is the dominant species after both floods (see species ordination for plot 3), but cannot compete with Ruppia megacarpa during low and steady flows. Plot 4 exhibits spectacular changes of trend which are caused by hydrological events. Convergence again occurs due to the persistence (sensu Connell and Sousa 1983) of Myriophyllum salsugineum and elimination of Lepilaena cylindrocarpa after high flow events.

The trajectory pattern for plots 1 to 4 can generally be described as frequently interrupted and sometimes converging. There is some evidence of cyclic behaviour, but trajectory trends are predominantly random after a high or low flow event. A cyclic pattern is more evident for plots 5 to 8 (fig 71 and 72) which do not undergo such extremes of chemical change.

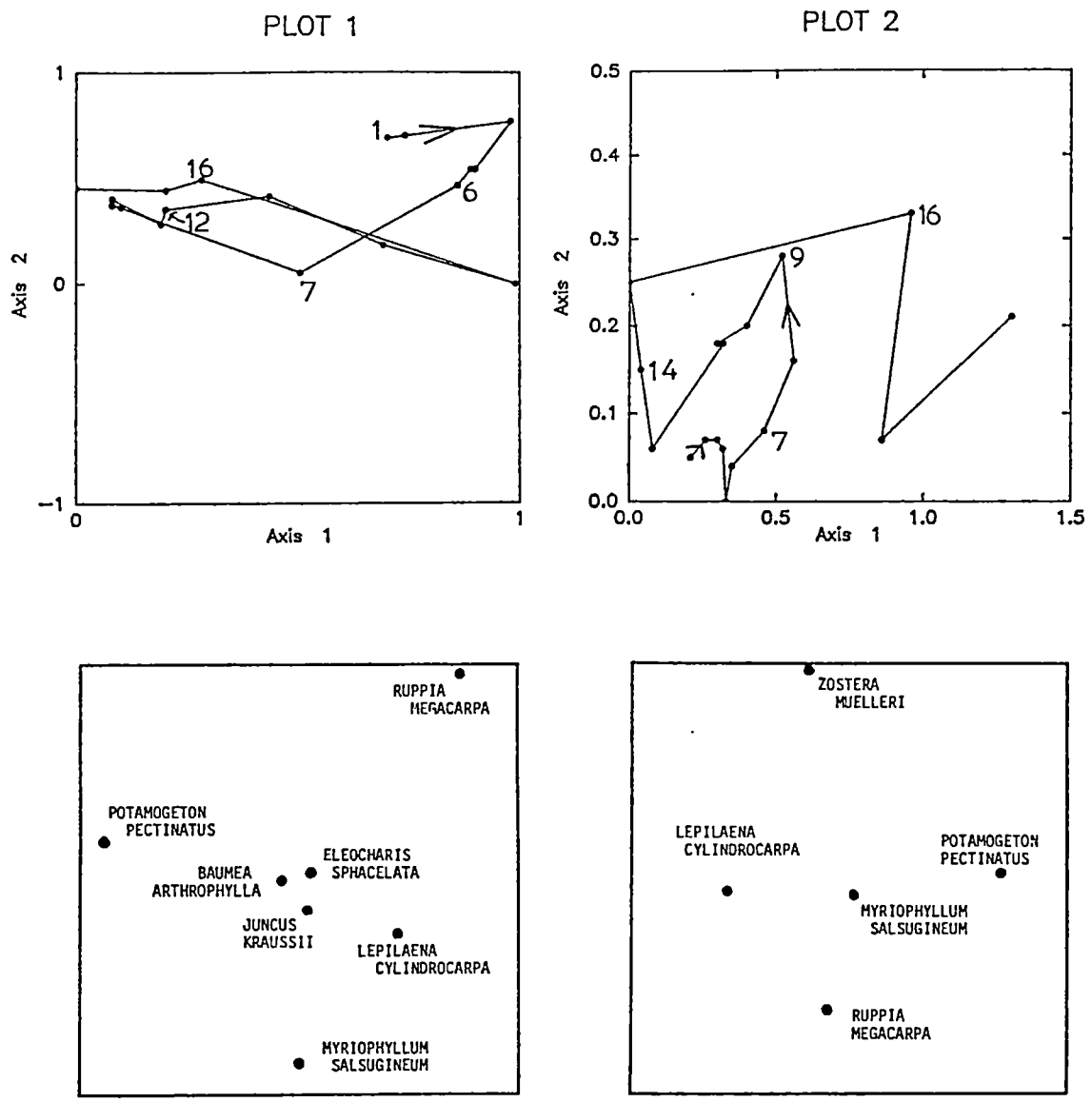


Fig. 69. Time trajectory (above) and associated species ordination (below) for plots 1 and 2

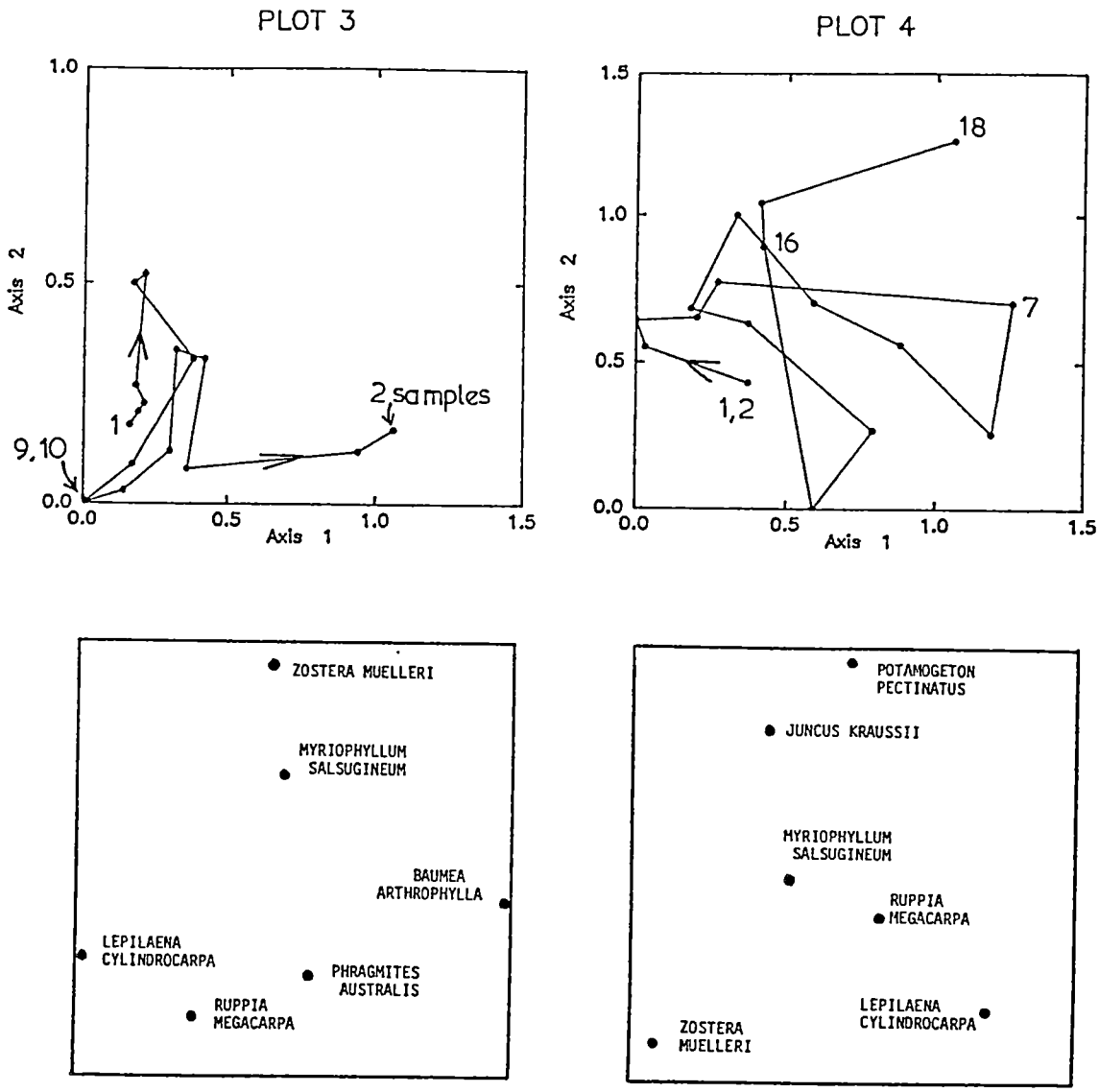


Fig. 70. Time trajectory (above) and associated species ordination (below) for plots 3 and 4

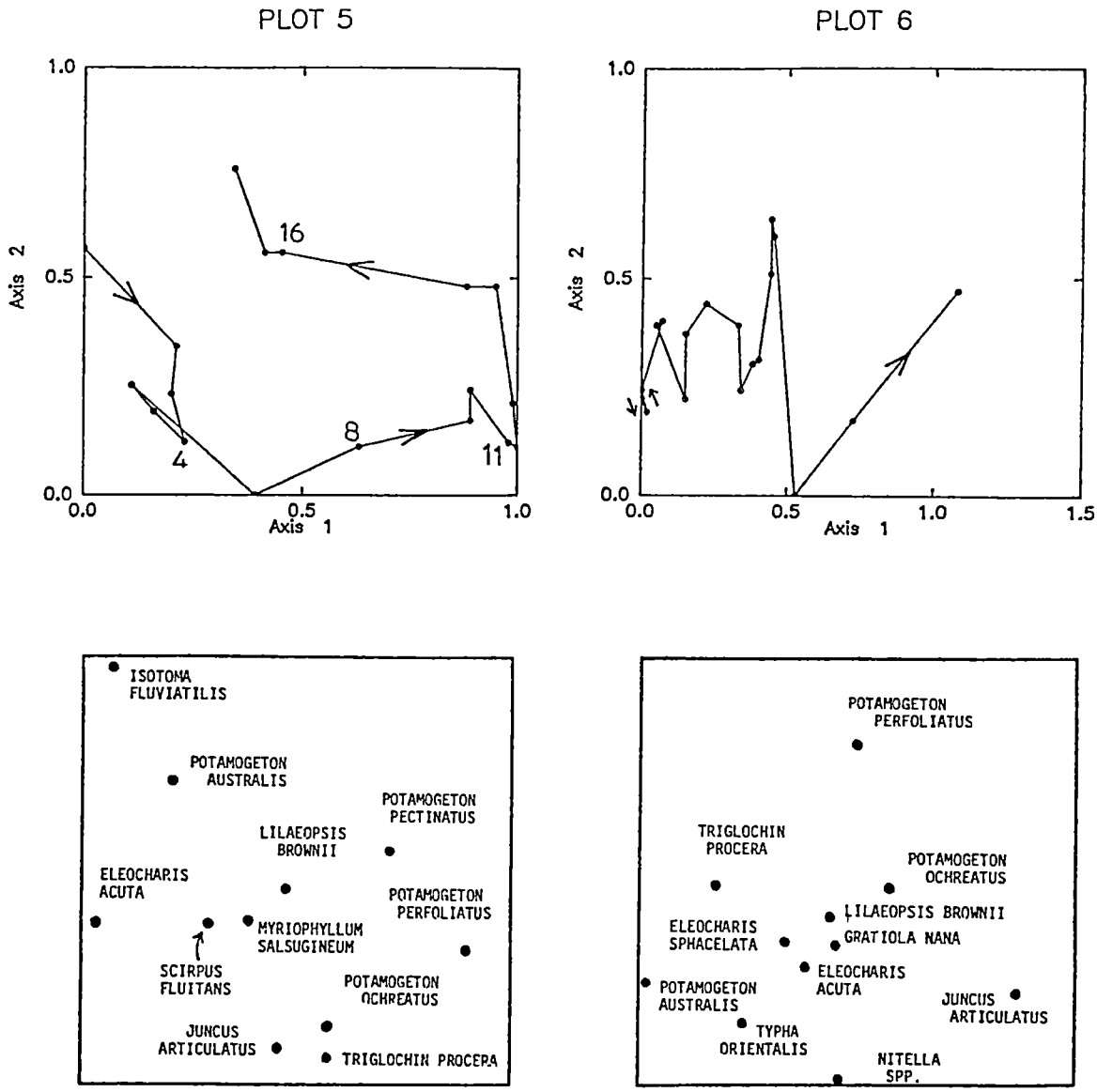


Fig. 71. Time trajectory (above) and associated species ordination (below) for plots 5 and 6

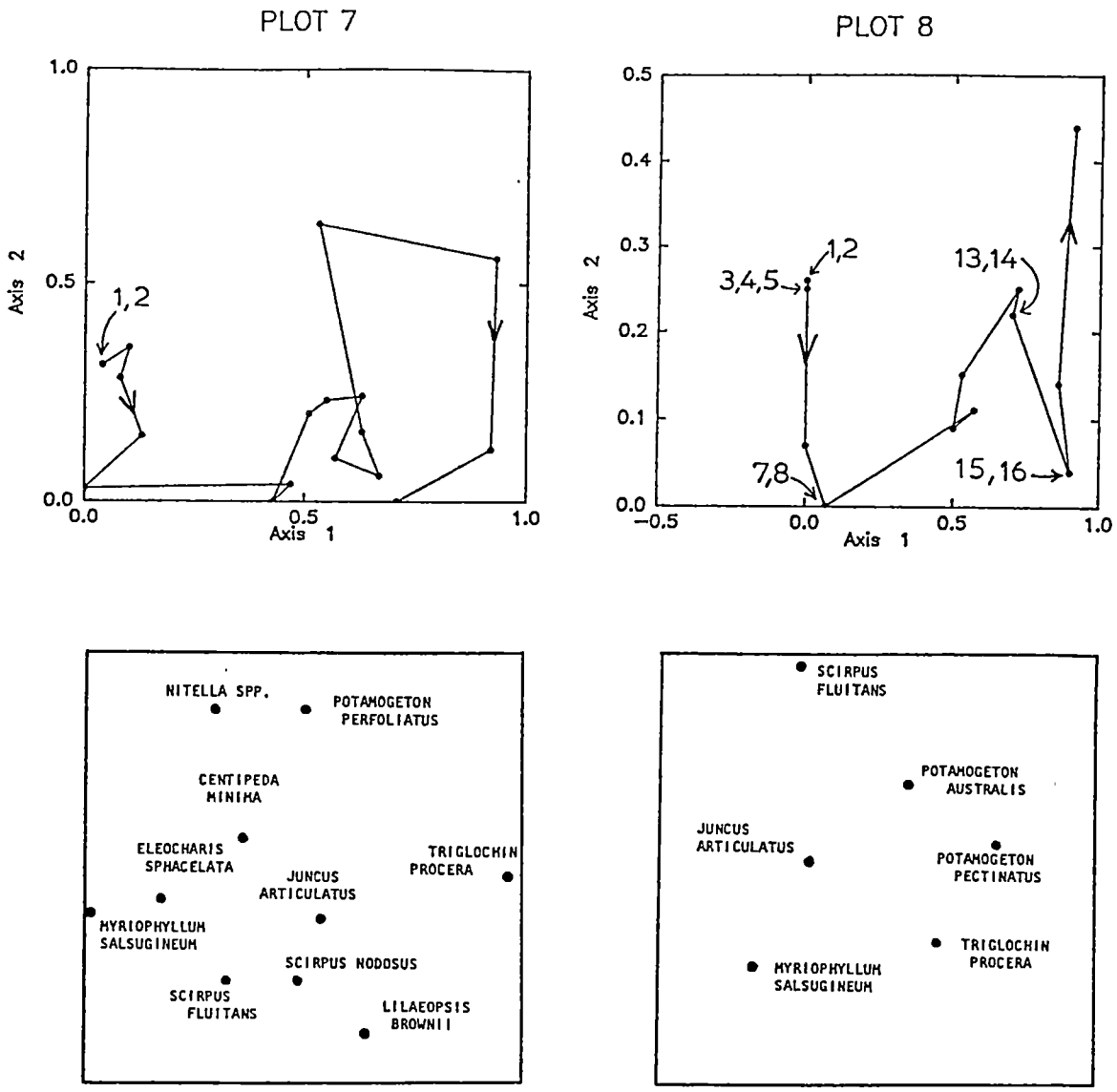


Fig. 72. Time trajectory (above) and associated species ordination (below) for plots 7 and 8

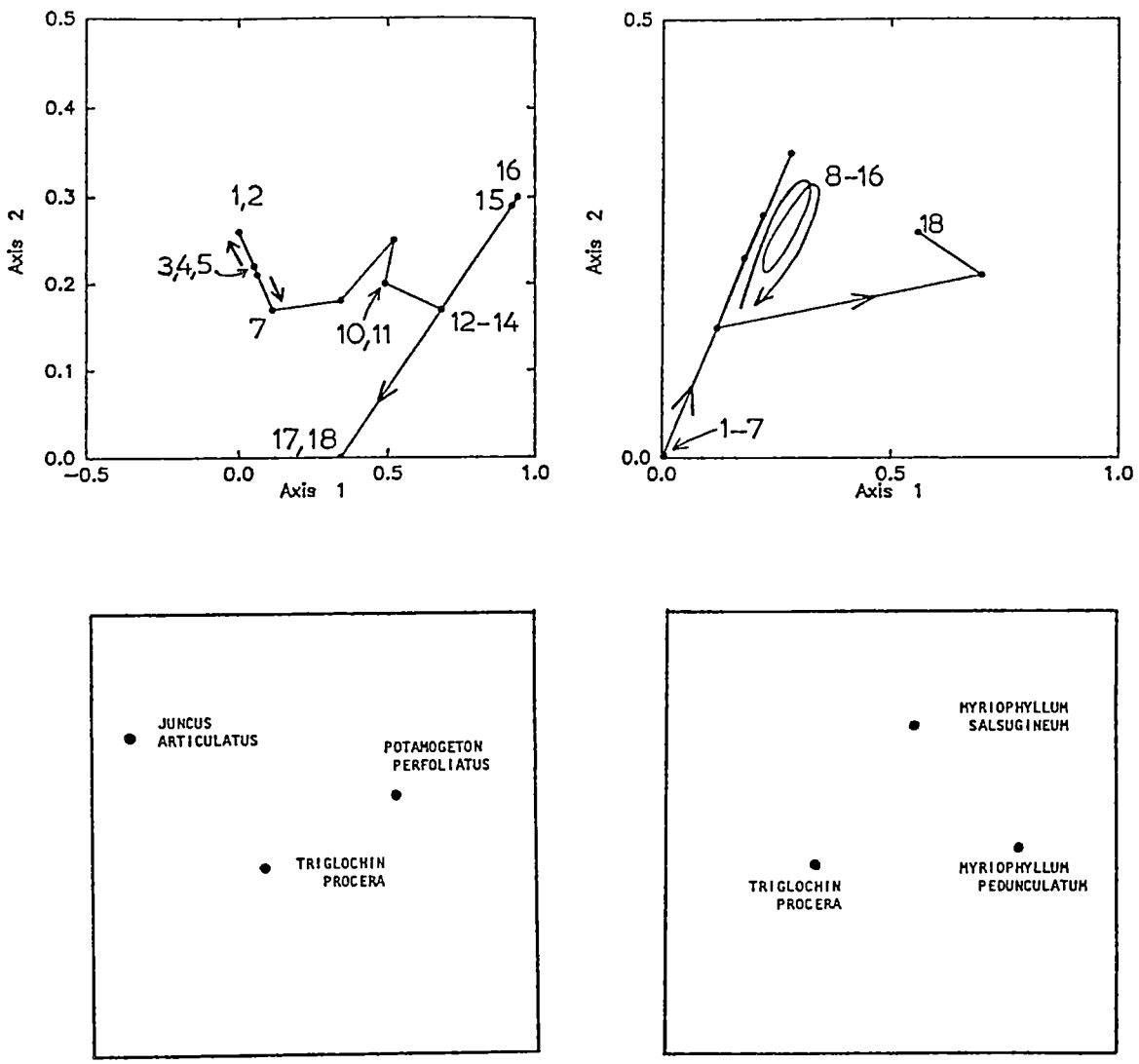


Fig. 73. Time trajectory (above) and associated species ordination (below) for plots 9 and 10

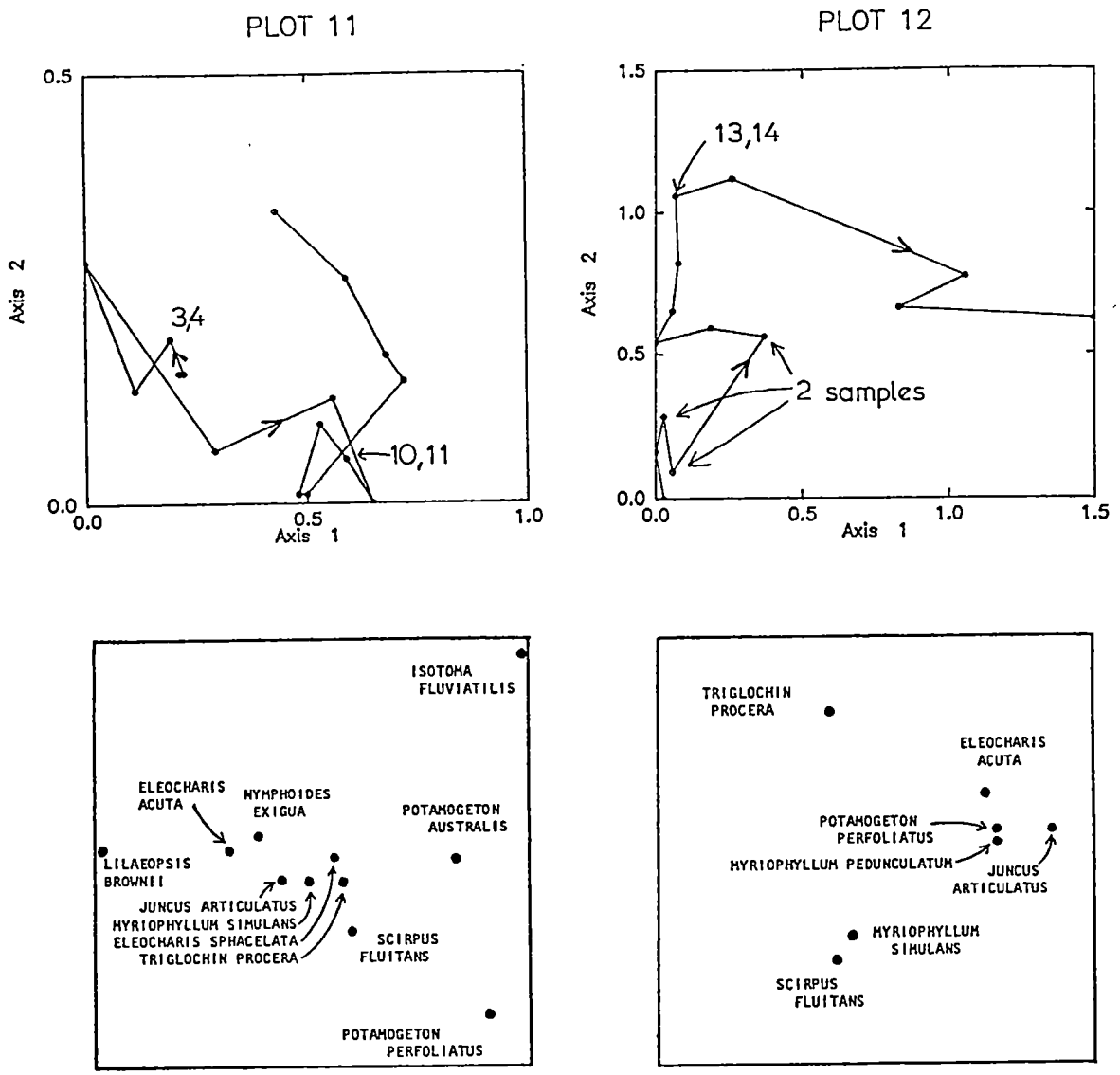


Fig. 74. Time trajectory (above) and associated species ordination (below) for plots 11 and 12

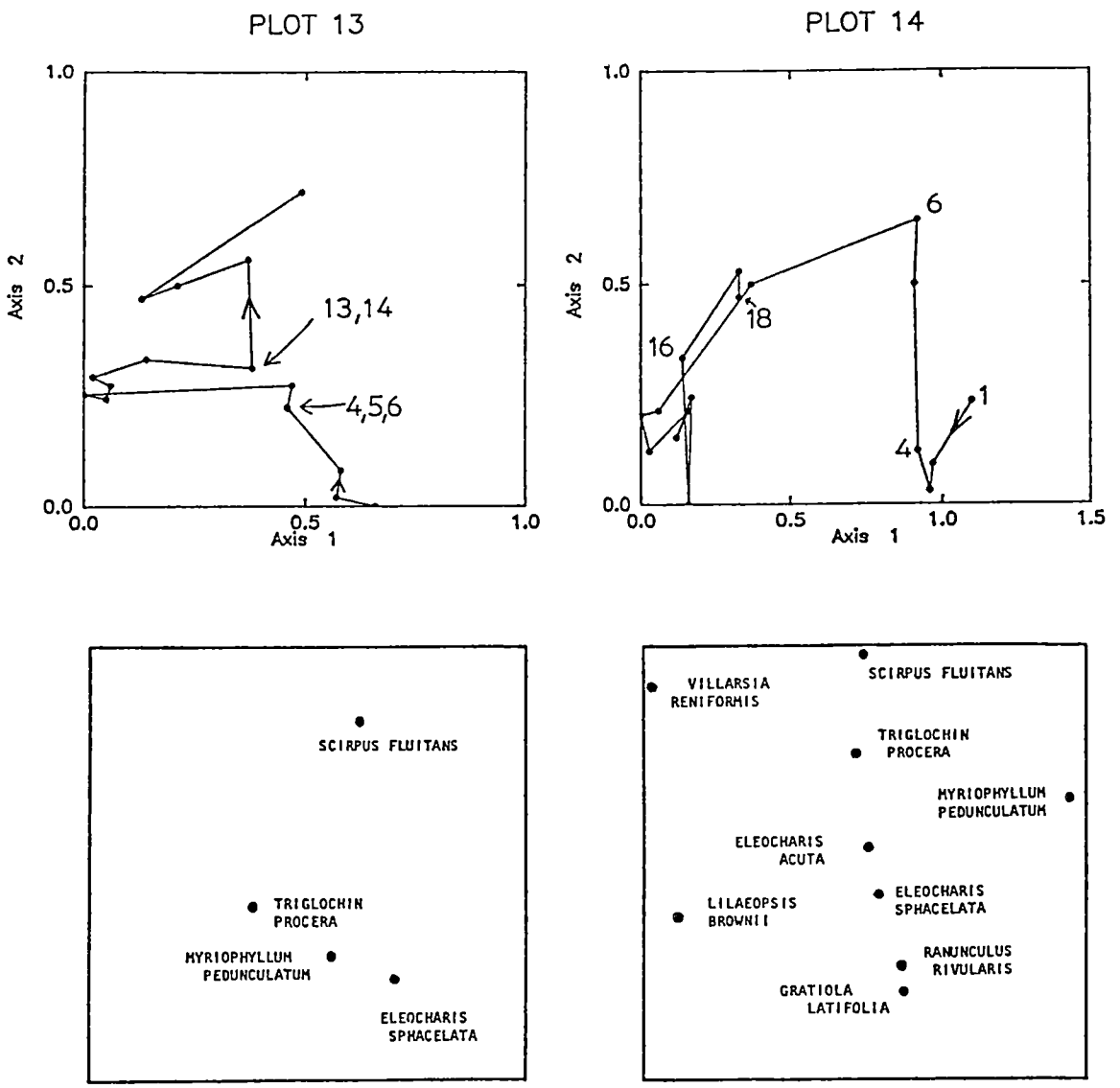


Fig. 75. Time trajectory (above) and associated species ordination (below) for plots 13 and 14

Plot 5 (mid reaches of the Swan River) displays a seasonal trend of increased total plot cover for samples 1 to 4. In June 1984 (sample 5) the hydrophyte Potamogeton ochreatus and the emergent species Juncus articulatus died back. This trend is obliterated in August 1984 by a winter flood, and in sample 8 Potamogeton perfoliatus and P. pectinatus are recruited. Eleocharis acuta diminishes during the summer of 1984-1985 as a result of lowering water levels decreasing moisture availability for marginal herbfield species, but the obligate hydrophytes Potamogeton perfoliatus, Myriophyllum salsugineum, Potamogeton pectinatus and Triglochin procera (morphological form D, after Robb and Ladiges 1981) increase (see direction of species ordination). A seasonal reversal of the trajectory occurs during the winter of 1985. The summer flood of 1986 reorientates the trend of the ordination by the elimination of Potamogeton perfoliatus and the recruitment of Isotoma fluviatilis.

Similar trends are evident for plots 6, 7 and 8. Plot 8 repeats samples in ordination-space, thereby demonstrating lack of change between hydrological events.

Plots 9 and 10 (fig 73) are found on unstable pebbly substrates and both experience a maximum species richness of 3. The random reorientation of trajectories is well illustrated for these two plots. Potamogeton perfoliatus is recruited in plot 9 after the August 1984 flood (sample 7) and Juncus articulatus is removed during the 1985 summer flood (sample 12). A final redirection of the trajectory occurs after the summer 1986 flood which eliminates Potamogeton perfoliatus. There are three main trends in the trajectory of plot 10 (upper reaches of the Swan River): pre-August 1984 flood (samples 1-7); cyclic pattern between August 1984 and September 1985 (samples 8-15); post-January 1986 flood (samples 16-18).

Plots 11 and 12 display repetition of samples in ordination-space, with major reorientation of the trajectory occurring after high or low hydrological events. Plot 14 (fig 75) is situated on the floodplain of the Apsley River by the causeway. Samples 1 to 3 were obtained during low flows from February to April 1984. The dominant species are Myriophyllum pedunculatum and Gratiola latifolia, which may survive in marginal herbfield conditions. Steady water levels from May to July 1984 (samples 4 to 6) encouraged the growth of Scirpus fluitans, Ranunculus rivularis, Triglochin procera and Eleocharis acuta. During the August 1984 flood Myriophyllum pedunculatum was eliminated, and replaced by Villarsia reniformis and Lilaeopsis brownii. The 1985 autumn flood did not affect the species composition of the plot, and the plot displayed a seasonal trend of decomposition and growth. A major shift in the trajectory occurred at samples 16 to 18 (1986 floods) during which Villarsia reniformis was eliminated from the plot.

In the ordination of the abundance data from each site, the major proportion of the variation is explained by axis 1 and this axis is plotted against time in figure 76. These ordinations highlight temporal changes in the vegetation with a marked transition for all sites in August 1984. Convergence of plots 1, 2, 3 and 4 is coincident with the three high flows experienced during the study period. Trends between these convergence points follow a seasonal pattern. Different patterns are displayed by the other plots, but there appears to be consistent reorientation following the summer 1986 floods.

3.4.4 Dissimilarity and randomness

An examination of dissimilarity between points in time will provide information on distance between points along the time trajectories. Thus large distances between points in ordination space will be reflected by high absolute Euclidean dissimilarity. Dissimilarity for each plot is

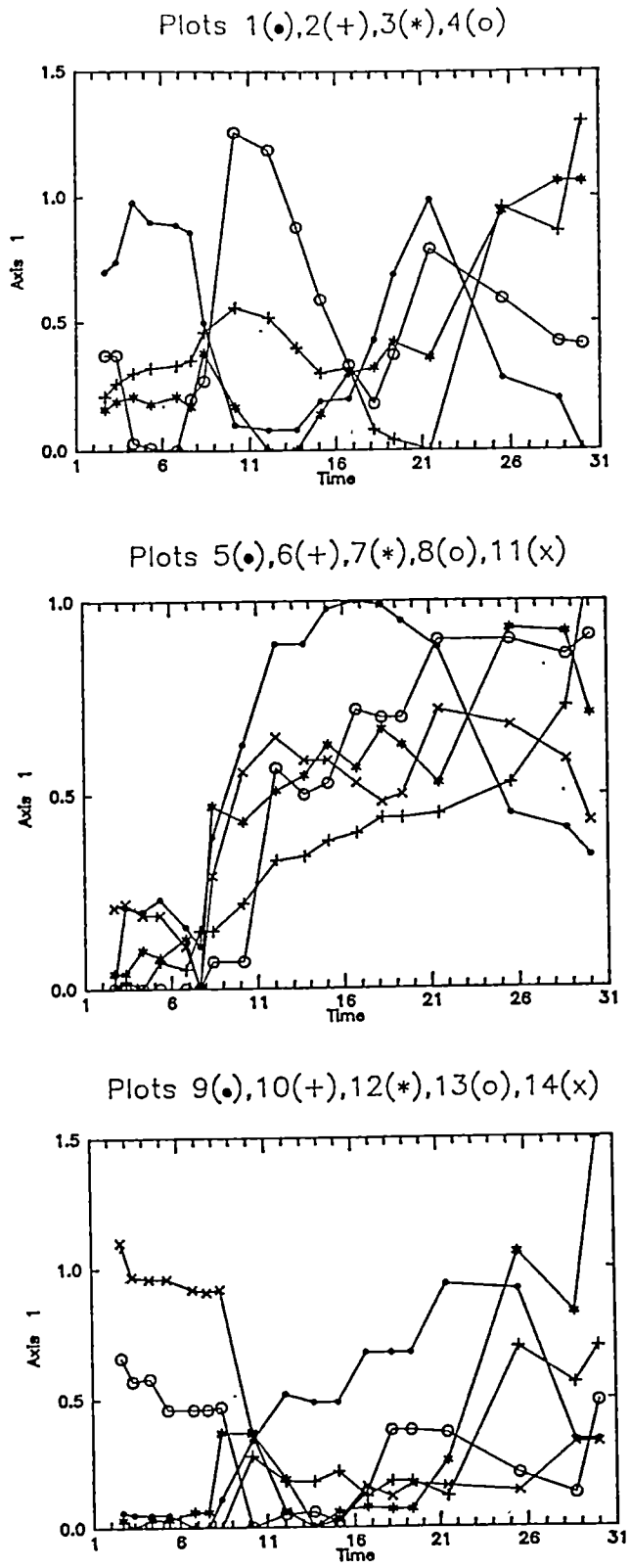


Fig. 76. Temporal changes in ordination scores (axis 1 only) for the 14 plots

plotted against time in figure 77. There appear to be consistent trends in dissimilarity for all plots. Plots 1 and 4 display marked dissimilarity after the August 1984 flood, and plots 1 to 4 increase in dissimilarity after the summer 1986 floods. Synchronous behaviour in dissimilarity over time appears evident for plots 5, 6, 7, 8 and 11 with the greatest dissimilarity occuring during the steady flows in September 1985. This pattern is less consistent for plots 9, 10, 12, 13 and 14.

The Pearson product moment correlation coefficient is used to test the null hypothesis that there is no significant synchronization in dissimilarity between any of the plots. All possible correlations are computed between the plots, and 29 of the 91 correlations are significant ($p < 0.10$). The significant correlations are displayed in figure 78, which indicates that each plot is positively correlated with one or more plots. The remaining 62 correlations are not significant, indicating that a general trend in dissimilarity is not evident for these plots.

Two hypotheses were tested to examine randomness in the ordination trajectories: a) Ho = the angle of direction of each plot trajectory does not differ significantly from a random distribution;
b) Ho = the angle of direction of trajectories at each time period does not differ significantly from a random distribution.
The observed distribution of angles (see section 3.3.3 for methodology) for each plot trajectory does not differ significantly from a random distribution ($D < D_{0.2}$), with the exception of plot 8 ($D > D_{0.05}$) i.e. the first hypothesis is accepted in 13 out of 14 cases. For plot 8, 10 out of 16 of the angles experience a change of less than 45°, indicating small or no change in directionality. The second hypothesis is accepted for 14 cases. At time periods 8 and 16 the angle of direction of the trajectories does differ significantly from a random distribution ($D = 0.321$ in both cases, which is larger than $D_{0.1}$). During the winter 1984 floods (time

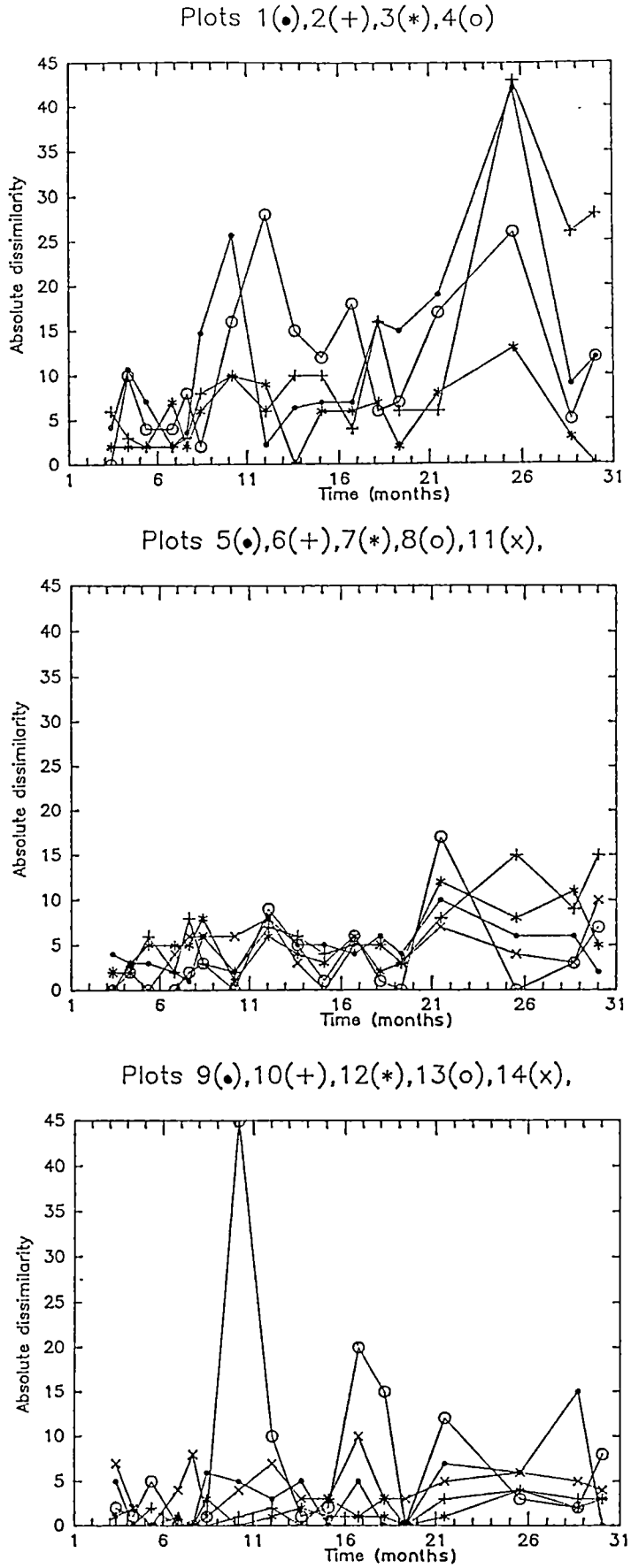


Fig. 77. Absolute Euclidean dissimilarity plotted against time for plots 1 to 14

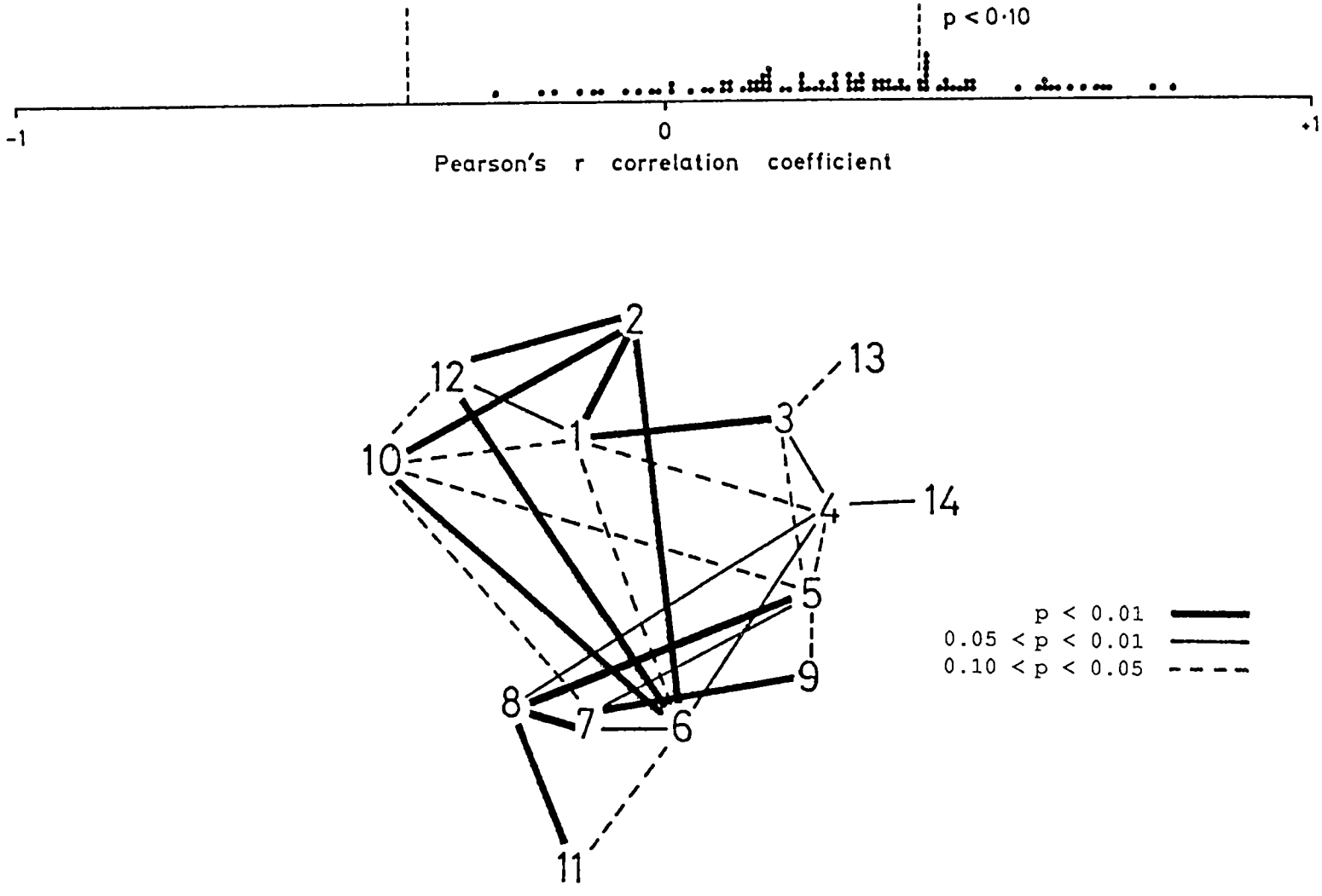


Fig. 78. Above: Frequency graph and significance levels of the 91 correlations of dissimilarity. Below: Plot constellation derived from correlations of absolute dissimilarity

period 8), 8 out of 14 of the trajectories experience a 180° change in direction. The same is true during the summer 1986 floods (time period 16).

The Pearson product moment correlation coefficient was used to compare the directionality of the 14 time trajectories, and the significant correlations are displayed in figure 79. Thirteen of the 91 correlations are significant ($p < 0.1$), but nine of these are negative. Negative correlations indicate that directionality between plots is inversely proportional i.e. not parallel. Positive correlations demonstrate parallel directionality, and this is the case between plots 6 and 8, plots 6 and 5, plots 2 and 9, and plots 4 and 7.

By plotting ordination trajectories through time, it is possible to observe (successional) trends in vegetation (Austin 1977, Austin et al. 1981, van Hecke et al. 1981). If the individual trajectories of permanent quadrats display parallel trajectories then a general successional trend is evident (Austin 1977). A random distribution of the trajectories is a possible indication of site-dependent trends, while individual plots displaying no consistent trajectory may reflect a lack of temporal patterns.

The 14 plot trajectories in this study display no parallel directionality, with the exception of four pairs of plots whose directionality is significantly correlated. There is thus no general trend of directionality over time, reflecting the individualistic behaviour of the 14 plots. The analyses demonstrate a random distribution of the trajectories at 14 time periods. At two of the time periods non-random directionality is attributed to flood events. Thus between high discharges, changes in vegetation appear to be site-dependent. During high discharges, vegetation changes are at a maximum. A random distribution is also evident for the individual plots with the exception of plot 8 which is sited on the middle reaches of the Swan River. Non randomness for plot 8 reflects a lack of directionality

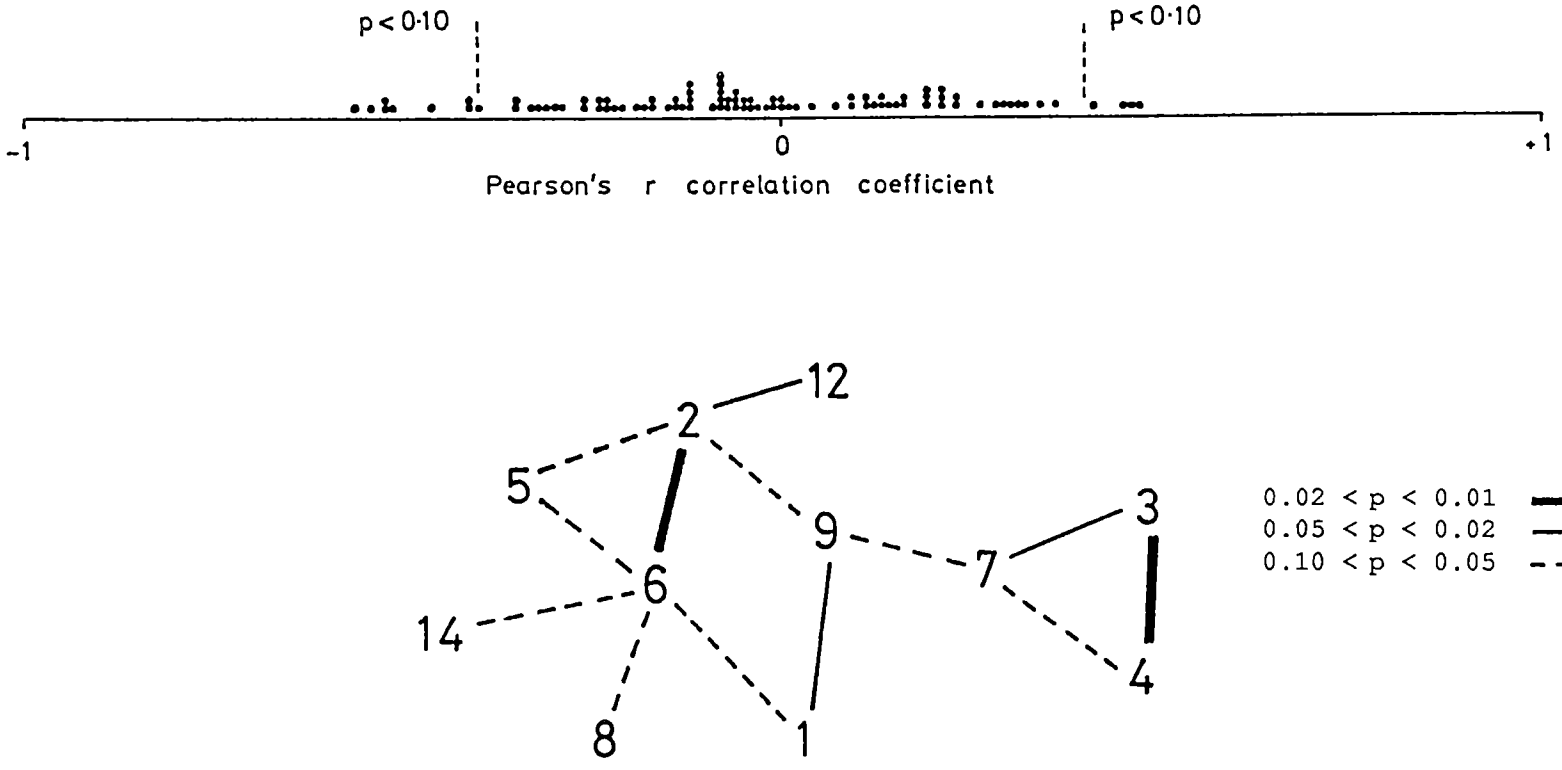


Fig. 79. Above: Frequency graph and significance levels of the 91 correlations of directionality. Below: Plot constellation derived from the correlations of the directionality of the trajectories

rather than a consistent trend, and this is caused by the even cover of species between disturbance events. The random distributions of the 13 plots are not altogether surprising given the sharp breaks in the ordination trajectories, and reflect an environment with repeated disturbances.

3.5 Discussion

Changes in lotic aquatic plant communities over time are potentially at their greatest in the eastern rivers of Tasmania, which experience high coefficients of variation of annual, peak and low flows. The range of discharges (from 20/2/84 to 1/6/86) for the Swan and Apsley Rivers on the central east coast of Tasmania was 0.01 to 609 cumecs and 0 to 213 cumecs respectively. During the study period there were 13 hydrological events greater than 50 cumecs for the Swan River at the Grange and 15% of average daily flows were less than 0.1 cumecs.

In this study the effects of disturbance were measured by examining displacement of community structure in 14 permanent quadrats. During high flows i.e. >50 cumecs, plot cover diminishes, species richness increases for 50% of the plots, diversity decreases along with evenness, and beta turnover increases. During discharges of less than 0.1 cumecs, plot cover increases, species richness remains unchanged, diversity increases along with evenness, and turnover does not occur. Steady flows allow plant cover to increase (in some cases) along with species richness. Species diversity tends to increase during steady discharges, indicating polydominance. Only one plot experienced species turnover during steady flow (plot 4 on the lower Swan River), and this was due to decomposition of Lepilaena cylindrocarpa. Superimposed on these predictions are seasonal ones. Plot cover is higher in summer than winter along with species richness. Neither species diversity nor evenness are affected by season, and the same

is true for beta turnover. The prediction that hydrological disturbance is accompanied by variability in community structure is thus supported.

These patterns are summarized in figure 80, which represents a simple model of change in aquatic plant communities with varying discharge and season for the Swan and Apsley Rivers. A winter flood is the most disturbing event for aquatic plant communities, in terms of plant cover and species diversity. Species turnover and richness increase, though this may induce competition and species dominance. Flooding at the end of winter (with dissemination through fragmentation) followed by a summer growing season ensures the survival of all persistent and recruited species in the community. During low winter discharges, plant cover does not decrease and there is species polydominance. If discharge conditions remain stable until summer, species richness will increase due to reproduction and dispersal of propagules. A summer flood diminishes plant cover and increases species richness and turnover. Conversely, species diversity and evenness decrease which encourages dominance of a few species. Low summer discharges encourage high plant cover, and high species richness is maintained. However, species diversity and evenness increase, and polydominance of species occurs.

Secondary loops and patterns may be added to the model: for example when there are several floods in one season or when there is prolonged drought across several years. These environmental conditions were not encountered in the study.

There are discrepancies in the model, and these are due to time of sampling, the occurrence of particular species, and the location of the plots. Plots sampled immediately after a flood may display a community structure that does not equate with the hydrological conditions measured at that time. This is especially the case for rivers on the east coast of Tasmania which rise and fall over the course of several hours. Thus in a sampling programme of this nature, it is

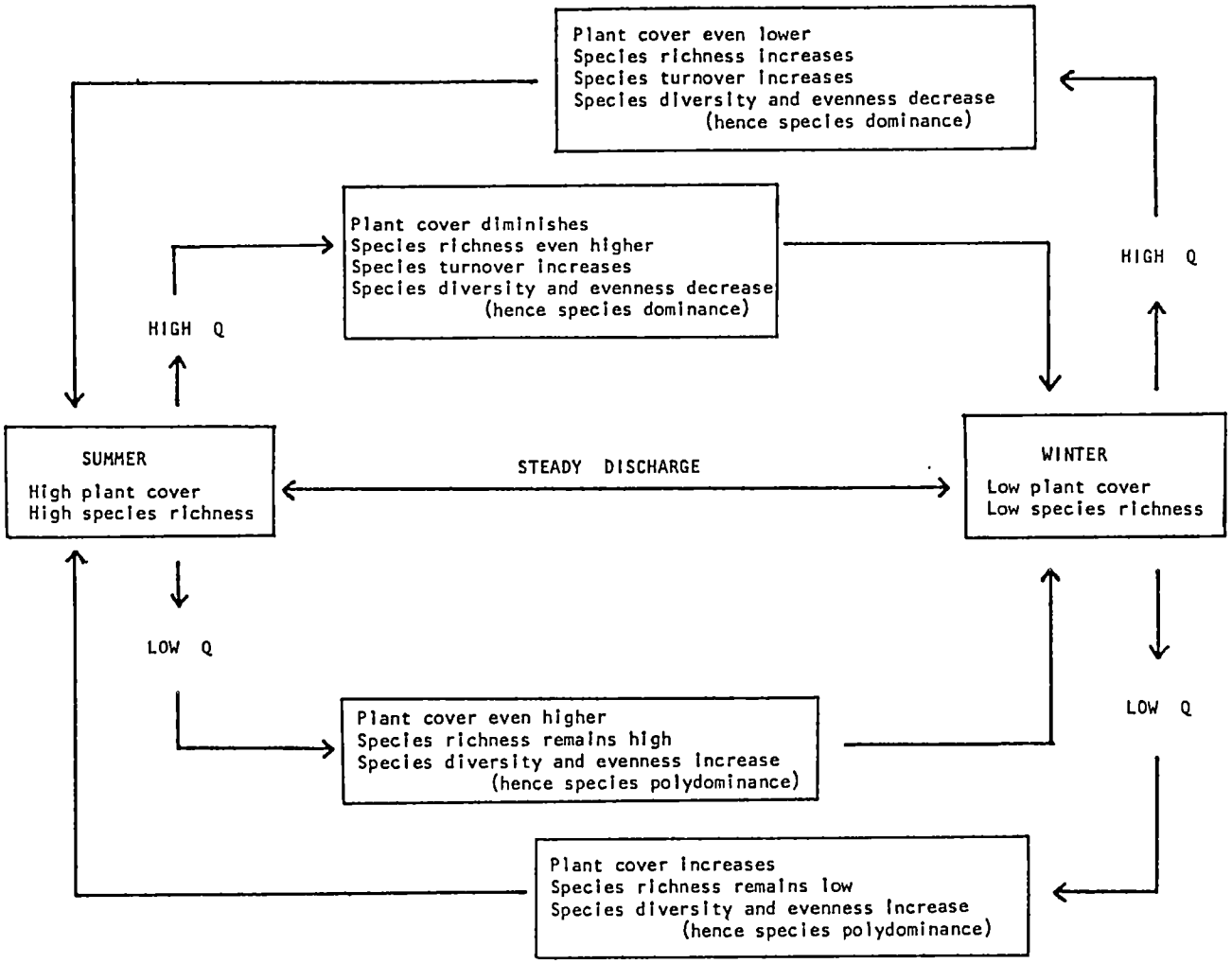


Fig. 80. Simple model of community structure with varying discharge and season, based on data collected from two rivers on the central east coast of Tasmania

essential that hydrological conditions at the time of plot sampling be recorded in terms of antecedent discharge events. Additionally, the timing of the disturbance may greatly influence the subsequent recovery, in terms of interruptions to the lifecycle of a species.

Some aquatic plants are better adapted to life in a disturbance environment than others (table 9) (and see Grime 1979, Mitchell and Rogers 1985, Sculthorpe 1967, Williams 1985, Wooten 1986, Noble and Slatyer 1977, Chesson 1986, Leakey 1981). Table 8 demonstrates how some species are persistent and resistant (Leps et al. 1982) e.g. Eleocharis acuta, Myriophyllum salsugineum, and hence (possibly) more tolerant of disurbance events. However, table 8 also demonstrates that those species resident for the entire study period are almost all marginal or herbfield species i.e. not obligate aquatics. Thus species turnover, diversity and richness are inevitably stable if such species predominate in a plot e.g. in plot 4, Juncus kraussii remains stable compared to Lepilaena cylindrocarpa. No plot was ever devoid of vegetation, or completely stripped after a flood or low discharge. Species richness and diversity recovered after discharges >50 cumecs though the same species were not necessarily present. Table 9 points out the traits important in recovery from discharge disturbances (cf. Grime 1979), but it must be remembered that discharge adaptation is a property of the whole life cycle of the species rather than of a particular trait. Species adaptations are important in determining whether a species can survive a given hydrological regime, but they can give little insight into the replacement sequence (succession) of communities containing them. In communities where competition is minimal due to the frequency of disturbance, adaptations (or vital attributes, sensu Noble and Slatyer 1977) are of primary importance when predicting recovery after a disturbance.

Plot location also adds to discrepancies in the model. Plot 6 is located in a cut-off channel on the Swan River, and during low and steady discharges resembles a lentic rather than a lotic environment. Richness, diversity and evenness are consistently high for plot 6, reflecting this periodically lentic condition (see Hillman 1986 for a review of billabong ecology).

Comparative data on species richness of lotic aquatic angiosperms are few. Dawson et al. (1978) recorded eight species of aquatic macrophyte in their study of an English chalk stream, though two of these species were codominant. Along a 50 metre stretch of the River Lambourn, England, Ham et al. (1981) recorded 20 species of aquatic macrophyte as well as the dominant species Ranunculus penicillatus var. calcareus. Holmes and Whitton (1977a) and Holmes and Whitton (1977b) list 17 aquatic angiosperms for the River Tweed, 12 for the River Tyne, 13 for the River Wear, 12 for the River Tees and 14 for the River Swale, in the north of England.

46 species of macrophyte were found by Wiegleb (1983) along numerous rivers in Western Lower Saxony (Germany), and Schloesser et al. (1985) identified a total of 10 species at their study sites along the Detroit - St. Clair river system in Canada. No comparative studies were found for mainland Australian rivers. However, as survey techniques used differ, it is difficult to compare results made by different authors. Nevertheless, it is evident that the aquatic flora sampled in the 14 quadrats along the Swan and Apsley Rivers (30 species total) is relatively diverse, though at any one time period, no more than 26 species were recorded.

These are pertinent results in the light of recent conceptual work for stream environments (Ward and Stanford 1983, Lake and Barmuta 1986, Lake 1986, Fox 1977). The intermediate-disturbance hypothesis (Connell 1978) predicts that biotic diversity will be greatest in communities subjected to moderate levels of disturbance, and Osman

(1977) states that 'there appears to be an optimal frequency of disturbance at which diversity is maximised'. Diversity in these studies was used as a synonym for species richness.

Species richness in the Tasmanian study increased after high discharges (for 50% of the plots) and remained unchanged during low discharges. Species diversity (using N_2 as a measure of species polydominance) decreased after high discharges and increased after low discharges. In stream habitats exposed to severe or frequent disturbance, species diversity is supressed, and the same is true for habitats with environmental constancy (Ward and Stanford 1983). It is evident from the Tasmanian study that high discharges (>50 cumecs) occur sufficiently frequently to maintain a relatively high level of species richness.

Several studies of changes in aquatic plant communities over time were found (Dawson et al. 1978, Wiegleb 1981b, Jones 1955, Schloesser et al. 1985, Ham et al. 1981). These studies were, however, conducted in temperate northern hemisphere environments. These data are used to compare results obtained in the Tasmanian study.

In their study of vegetation succession in a chalk stream (Bere Stream) in southern England (from 1968 to 1972), Dawson et al. (1978) concluded that the Rorippa-Ranunculus community had reached a climax state. This community was considered stable because although the regular changes in the flow cycle exerted an important influence on the vegetation, the species were able to adapt to life in the stream. The adaptation suggested by the authors was seasonal variation in production and biomass, ensuring long-term residence and persistence of both codominant species. It was also concluded that the Rorippa-Ranunculus community had inertia and was able to resist external perturbations. Thus it is stated that provided adaptive mechanisms can be demonstrated and that communities are stable, the vegetation of rivers can be regarded as a climax. The community growing

in the chalk stream is described as a 'cycloclimax', where generations are timed to regular annual discharge fluctuations (there are no floods in chalk streams). Their results can also be interpreted from the point of view that codominance (or low species diversity) is a result of the constancy and predictability of discharge in the chalk stream.

This regular pattern of community structure (i.e. changes in production and biomass for two species) described for a chalk stream in southern England, represents a very different picture to that found along the Swan and Apsley Rivers. The plant communities studied in eastern Tasmania display no regular changes in structure, and reflect a random hydrology. Changes in community structure are related to high, low and steady discharges as well as the consequent changes in water chemistry. There was no evidence of competition occurring between these events, though high and low discharges happened sufficiently frequently to curtail such processes. Most importantly, the process of recolonization and species growth following a disturbance in the Tasmanian study is better explained by the life-history characteristics of the individual species rather than by any emergent properties (Salt 1979) of the whole community (table 9).

The pattern found by Dawson et al. (1978) differs to that found by Ham et al. (1981) along the River Lambourn. This is a chalk stream dominated by Ranunculus penicillatus var. calcareus, but the timing of the growth cycle is later than for Bere Stream. Additionally, Rorippa nasturtium/aquaticum is present on the Lambourn site in shallow marginal areas only, and is unable to colonize the main channel with Ranunculus. It is suggested that the delay in the growth cycle of of Ranunculus in this study is related to the absence of emergent macrophytes, though Brooker et al. (1978) have demonstrated an inverse relationship between growth of Ranunculus and flow (from April to June) in the River Wye which has a greater range of discharges than a

chalk stream.

Schloesser et al. (1985) attributed species succession (which is not defined in the study) of some taxa in the St. Clair-Detroit River system to species competition or differences in taxon life cycles (i.e. adaptations). Three seasonal growth patterns were evident: one dominant taxon grew alone e.g. Myriophyllum spicatum, Elodea canadensis; sympatric growth of codominant taxa without species seasonal succession e.g. Vallisneria americana grew simultaneously with three to five other taxa; sympatric growth of codominant taxa with species seasonal succession e.g. Potamogeton spp. was replaced by Potamogeton richardsonii by late August, which was replaced by Elodea canadensis in late October. Effectively these patterns could be quantitatively translated into species dominance, polydominance and turnover respectively. This study was undertaken during the course of one season, thus precluding the possibility of more than one growth pattern occuring in the same community. It is presumptuous to label these changes in community structure as 'species succession', without identifying progressive and predictable processes leading towards some stable, equilibrium condition (however this climactic state might be conceived). The study gave no consideration or evidence of changes in vegetation structure being related to external, density-independent environmental events.

Wiegleb (1981b) examined changes (% cover) of aquatic macrophytes along six 50 metre sections of the Delme and Lethe Rivers (W. Germany) between 1978 and 1981. There was great seasonal variability of plant cover, with virtually no aquatic vegetation recorded in winter (with the exception of Phalaris arundinaceae, Glyceria maxima and Sparganium emersum). The study concluded that aquatic plant communities along these two rivers were very unstable, although the degree of instability was not quantified. Butcher (1933) also noted the impermanence of vegetation in the River Itchen. He charted vegetation along the two rivers over a period of three years, and it was evident that the biomass

of a particular species varied as well as its locality.

Jones (1955) undertook a detailed study of species cover over time in two permanent quadrats in the River Rhiedol, Wales, between 1946 and 1952. This was an innovative project that used the technique of vegetation mapping for recording the plant cover of natural and introduced (specimens were propagated in hessian bags placed in the river bed) aquatic vegetation. Several pertinent inferences may be made from the findings of this study. There were no floods during the period of observation, and competitive replacement of species occurred between Callitriche and Glyceria in quadrat 1. Potamogeton polygonifolius became established in 1947 in this quadrat as a result of the shelter provided by the increase in Glyceria and Callitriche. In quadrat 2, there was a progression from aquatic vegetation to an emergent 'swamp' community (Callitriche to Glyceria to Agrostis) due to an obstruction upstream creating a backwater. Jones infers that floods may scour out much of the aquatic vegetation, inducing the cycle to begin again and proceed to a subclimax that is determined by current speed. In the absence of floods internal density-dependent mechanisms appeared to operate.

No other data were found examining changes in lotic plant community structure over time. However, aquatic vegetation changes (species composition and plant cover) in a lentic situation were studied over a 10-year period in Saskatchewan, Canada, by Millar (1973). He found that emergent species such as Eleocharis palustris decreased in density when there was a 'greater-than-normal' water depth at the start of the growing season, but two or more years of continuous flooding were needed to eliminate the emergent cover completely and convert the wetland to open water. Repeated autumn reflooding also resulted in complete elimination of emergent species. Interestingly, Millar classified Alopecurus aequalis, Beckmannia syzigachne, Glyceria grandis and Glyceria pulchella as 'disturbance' species because of their tendency to appear wherever there

was an exposure of soil. Dominance of a basin by these species was used as an indicator of environmental instability, either due to human-induced disturbance or natural causes.

Various temporal studies exist for Australian stream fauna. Bunn et al. (1986) studied changes of the macroinvertebrate fauna of streams in the northern Jarrah forests of Western Australia. The climate and hydrology of this area is, by Australian standards, quite predictable with the highest stream discharges occuring in winter. The authors investigated temporal changes in abundance, diversity and evenness of the invertebrate fauna, which became dominated by a few taxa during the summer months. The temporal changes were associated with seasonal changes in discharges.

In south-eastern Australia, seasonal changes in the fauna of streams do not appear to show any generalized patterns. For example, investigations by Lake (1982), Marchant et al. (1985), Lake et al. (1985) demonstrate low densities of invertebrate taxa in summer, while Marchant et al. (1984) found the highest densities in summer and spring. Similar results were found for the invertebrate fauna of New Zealand streams by Winterbourn et al. (1981). These results probably reflect erratic stream hydrologies rather than aseasonality.

Ordination and classification highlighted the spatial distinctiveness of the plots. The initial division was between plots occuring in the saline mouth of the Swan River (indicator species Lepilaena cylindrocarpa and Myriophyllum salsugineum), and those in the freshwater component. Within the freshwater component, plots are divided into those occuring on the cobbly upper reaches of the Swan and Apsley Rivers (indicator species Myriophyllum pedunculatum, Triglochin procera, Myriophyllum simulans), and those occuring on the midreaches of the rivers (indicator species Lilaeopsis brownii, Juncus articulatus, Potamogeton perfoliatus). Vannote et al. (1980) have indicated that the

highest biotic diversity occurs in the midreaches of streams, where there is highest environmental heterogeneity, and that headwaters and lower portions of rivers have lower diversity values associated with a more constant environment. The classification of freshwater plots supports this concept. Plots in the midreaches of the Swan and Apsley Rivers have higher species richness ($\bar{S}$=8.6) than those in the upper reaches ($\bar{S}$=3.8). Plots in the saline reaches of the Swan River have an average species richness of 5.4, which reflects an environment with frequent disturbance in terms of water chemistry (tidal).

Percentage cover of vegetation is greatest for plots in the lower Swan River ($\bar{X}$=58.9%) and lowest for plots in the upper reaches of both rivers ($\bar{X}$=22.6%). Plots in the midreaches have an average cover of 38.7%. N_2 (or polydominance) is highest for group 3 plots which are sited in the midreaches of the rivers ($\bar{N}$=6.6), and plot 6 has the greatest average polydominance (this plot is sited in a cut-off channel). Plots 9, 10, 12 and 13 (group 4) have low polydominance ($\bar{N}$=2.04), though plot 14 has N_2 of 6.32. This latter plot is on a periodically inundated floodplain of the Apsley River by the causeway, and supports herbfield species. Average diversity for the four plots in the lower Swan River is 4.05. Similar spatial patterns are evident for evenness. Beta turnover is not as spatially distinctive as the above variables, but the lowest average turnover occurs for plots on the midreaches of the rivers.

Similarly, Bunn *et al*. (1986) found large spatial differences in community structure of macroinvertebrates over small distances in two similar-sized catchments in Western Australia. These differences were attributed to concentrations of cations, reflecting differing geologies.

The ordination trajectories in this study are not comparable with those reported from other investigations. Austin (1977) presented continuous plot data for a garden lawn in London, U.K. The time trajectories for five quadrat blocks are

plotted and the directions are linear and parallel, suggesting a successional trend in vegetation change. Even when individual plots are ordinated and plotted through time, linear trends are the general pattern. Likewise the investigation of van Hecke et al. (1981) to determine changes in species composition and diversity with different fertilizer treatments.

Dissimilarity was used to investigate the rate of change between successive points on the trajectories as indicated by the distance between points, and to find out if the rates of change were synchronous. Rates of change were most similar between plots in classificatory group 3, though the majority of plots were synchronized with groups outside their classificatory group. Rates of change were greatest for plots 1, 2, 4 and 13 (in the upper and lower reaches of the rivers), and least for the midreach and some of the upper catchment plots, suggesting greater resistance of these communities.

Directionality of the trajectories was random for all plots with the exception of plot 8, and random at all time periods with the exception of time periods 8 and 16. Non-randomness of directionality occurred after the 1984 and 1986 floods (the two largest during the study period).

Stability of assemblages may occur through resistance (Harrison 1979, Leps et al. 1982), the ability of a system to withstand environmental disturbance, resilience, the ability of a system to recover rapidly following a disturbance (Connell 1978, Leps et al. 1982), and persistence, which is the constancy of community structure over time (Harrison 1979, Grossman 1982). Equilibrial communities are regarded as either resistant to disturbance or highly resilient after disturbance, both of which result in high persistence of relative abundances of species within the community over time (see Chesson 1986), whereas the converse applies to non-equilibrial communities (Grossman 1982).

In the Tasmanian study, the results demonstrate that the aquatic plant communities studied had low persistence. The same seasonal cycle did not persist from year to year (unlike the study of Dawson et al. 1978) and there were no repeated patterns. Possibly over a much longer time period (e.g. a 15-year period), repeated sequences of community structure would emerge. Certainly in this study (28 months), any hint of seasonal patterning was strongly overridden by the effects of perturbations. An assessment of persistence also depends upon the life cycles of the species (Connell and Sousa 1983), being highly variable for aquatic angiosperms which do not flower annually, and on the spatial scale on which the observations are made. Ogden and Ebersole (1981) pointed out that processes that are 'probabilistic on a small scale may sum to determinism on the large scale'.

The communities of aquatic macrophytes in this study showed little resistance to perturbations in terms of community structure, though this was variable along the rivers, and particular to the scale of operation. Plots in the midreaches of the streams displayed the greatest resistance. The results further demonstrate a lack of resilience for the community as a whole, and total randomness of directionality of change over time.

This study concludes that nonequilibrial or stochastic processes (i.e. discharge fluctuations) are important in regulating assemblages of aquatic plants along the Swan and Apsley Rivers. The evidence of site-specific succession does not support an organismic interpretation, and disturbance tends to favour opportunistic species that recover rapidly vegetatively (though not necessarily displaying the same structural characteristics) (cf. Grime 1979) i.e. low resilience at the community scale but high resilience at the species scale. There is a tendency towards species polydominance which supports an individualistic, abiotic interpretation of community structure and change.

Chapter 4

The vegetation of the Swan and Apsley Rivers

An Ode to Riparian Protection

I entreat we extol,
Riparian control

'Though many riparian,
Is largely agrarian -
Or removed by the axe,
To save corporate tax.
Inputs from this zone,
May suffice all alone -
As the energy drivers
of stream bio-survivors.

Leaves in the stream,
Are the substrate supreme.
"With microbes they're better,"
Says an invertebrate shredder -
They're ever so munchy,
With hyphomycete fungi.

And so I implore,
Let's work to restore -
Our riparian green,
To conditions once seen.

This <u>is</u> the correction
The real Stream Protection.

(K.W. Cummins, 1986)

4.1 Introduction

Recent stream ecological work has emphasized the structural and functional continuity of lotic ecosystems (Vannote et al. 1980, Newbold et al. 1981, Elwood et al. 1983, Fisher 1983, Minshall et al. 1983, Bott et al. 1985, Minshall et al. 1985). This approach contrasts to studies by Macan (1961), Illies and Botosaneanu (1963), Hynes (1970), Botosaneanu (1979), which consider rivers to comprise a series of well-defined, natural units with abrupt changes from one type of community to another.

Many of the earlier river zonation schemes were based on distributions of fish e.g. Carpenter (1928), Huet (1949). Although the concept of longitudinal fish-faunal zones is useful in river and fish management, it is obviously limited due to historic, geographic and climatic influences, and its (possible) invalidity in terms of other biocoenoses. There are numerous studies on longitudinal distributions of insects along rivers (see Hawkes 1975, Hynes 1970, Wright et al. 1984a, Wright et al. 1984b), and most conclude that invertebrates, like fish, are mostly longitudinally distributed, with different species occupying different sections of the stream. Pennak (1971), however, is critical of the use of taxonomic criteria alone for river-zone classification (see Furse et al. 1984) and recommends a group of thirteen physical and chemical parameters, including two floristic features (rooted aquatics and streamside vegetation).

Based from studies of European, African and South American streams, Illies and Botosaneanu (1963) proposed that streams could be divided longitudinally into upland rhithron and lowland potamon zones and that, in turn, each of these zones was divisible into three sections. This classification was based on physical as well as biotic criteria. Williams (1976) suggested that this scheme be examined in Australian streams. The Coal River in Tasmania (Bennison 1975), the

Acheron River in Victoria (Macmillan 1975) and the Bass River in Victoria (Gooley 1977) have been studied (Lake 1985), which indicated that while the rhithron can be discerned from the potamon, there is no clear subdivision within these zones.

There has not been such a proliferation of classification schemes for riverine vegetation. However, Tansley (1939) did use macrophytes as a basis for classifying rivers in Britain into five zones, but his work is largely based on that of Butcher (1933). Recently, several studies have emerged examining distributions of plant communities (aquatic and riparian) along rivers in northern Europe (Nilsson 1981, Nilsson 1983, Nilsson 1986) and Britain (Merry et al. 1981, Curry and Slater 1986, Goriup 1978, 1979, 1981), and the influence of riparian vegetation on the stream ecosystem has been stressed (Cummins 1986, Kaushik and Hynes 1971, Seddell and Froggatt 1984, Triska 1984, Dawson 1976b), and for Australian streams by Bunn (1986), Pidgeon and Cairns (1981) and Lake (1985). It is apparent that the terrestrial-aquatic relationship is an interdependent one, with the riparian and stream components being so tightly coupled that they most logically constitute a single ecosystem (see Cummins 1986, Hasler 1975).

It is surprising that few studies have related riparian vegetation to physiographic variation or flood regime as a means of explaining and describing longitudinal and cross-sectional patterns. The available work for temperate latitudes includes that of Sigafoos (1961), Nanson and Beach (1977), Teversham and Slaymaker (1976), Yanosky (1982), Hupp (1982), while Hughes (1984) has studied a tropical river.

In Australia little descriptive, let alone ecological, work has been undertaken for river vegetation (aquatic and riparian). In general, work describing riverine vegetation in Australia is usually placed under the heading of 'wetland' communities, and receives a brief mention after a description of the vegetation of lakes and other stationary

water bodies. The most comprehensive study is that of Beadle (1981) who describes communities along inland watercourses in Australia. Similar descriptive ecological work has been published by Briggs (1981) and indirectly by various workers in 'Ecological Biogeography of Australia' edited by Keast (1981). More recently Paijmans et al. (1985) published an overview of Australian wetlands which subdivides wetlands into six categories, including one on the vegetation of river channels. Unfortunately the vegetation of this category is not described in any detail. Various Australian studies have, however, been conducted in relation to the conservation of riparian vegetation in stream ecosystems (Helman and Estella 1983, MacMillan 1984, Blyth 1984, Campbell 1986b). No research has been undertaken on riverine plant communities in Tasmania, though the plant communities of Tasmanian wetlands have been described (Kirkpatrick and Harwood 1983a), and their conservation discussed (Kirkpatrick and Harwood 1983b).

This chapter examines the distribution of aquatic and riparian vascular plants at the catchment scale, along the Swan and Apsley Rivers in Tasmania, with the aim of elucidating whether plant species and/or communities are distributed in a continually varying fashion downstream in response to a 'continuous longitudinal gradient of environments' (Vannote et al. 1980), and whether diversity is highest in the midreaches of the streams. The absence of (apparent) discontinuities (unless anthropogenically induced) makes riparian plant communities suitable for studying clinal characteristics of a river. To this end, cross-sectional variations in vegetation (across the river channel) are further examined in relation to flow frequency, flow duration and substrate characteristics. Distributions of aquatic vascular plants are related to the riparian communities in order to assess the influence of the terrestrial setting of the stream.

4.2 The study area

The study was conducted along the Swan and Apsley Rivers on the central east coast of Tasmania, which both experience high fluctuations in discharge (chapter 2). The water chemistry of both rivers ranges from oligotrophic in the headwaters to mesotrophic in the lower reaches. Aspects of the water chemistry of the Swan and Apsley Rivers are summarized in table 11, and are described together with the hydrology, geology and landuse in chapter 3 (sections 3.2.2 and 3.2.3).

4.3 Methods

4.3.1 Vegetation sampling

The fieldwork was undertaken along the Swan and Apsley Rivers during the Austral summers of 1983 to 1984 and 1984 to 1985. Previous investigations examining distributions of riverine plants (henceforth meaning riparian and aquatic) have recorded presence/absence data of plant species along large sections of river, ranging from 50 metres (Goriup 1979) to 1 km (Curry and Slater 1986), and regardless of cross-sectional variation. In this study, where interrelationships between plant distributions and physiographic features are being examined, a more detailed sampling framework is required.

In the lower reaches of the rivers, where the channel is wider and the water table higher, a marked band of riparian vegetation is evident. However, in the middle and upper parts of both catchments, where the topography is steep, there appears to be less distinction between riparian vegetation and that growing in the rest of the catchment. Thus, vegetation was sampled up to, and beyond, the limit of the 1 in 10 year flood (see fig 49), which represents a discharge of 609 cumecs for the Swan River at the Grange.

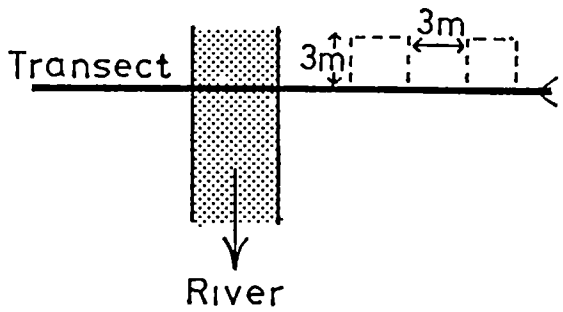
	Jetty road	Grange	Hardings Falls	Upper Swan	Apsley weir	Causeway	Rosedale
	1	2	3	4	5	6	7
Temperature (°C)							
N=		21	11	7	16	8	9
$\bar{X}$		13.5	11.7	9.9	13.3	13.7	11.9
Range		6.5 - 19.5	6.5 - 22.5	6 - 14	8 - 19.5	8.5 - 19.5	8 - 19.5
pH							
N=	8	25	8	8	15	3	4
$\bar{X}$	7.13	7.24	7.07	6.9	7.31	7.06	7.05
Range	7.1 - 7.3	6.5 - 8.1	6.3 - 7.6	6.4 - 7.3	6.7 - 8.1	7.0 - 7.2	6.9 - 7.2
Non filterable residue (p.p.m.) N=	8	24	7	7	14	8	8
$\bar{X}$	1.6	1.5	1.7	0.004	1.9	2.0	1.3
Range	<1 - 3	<1 - 7	<1 - 3	0.001 - 0.009	<1 - 5	<1 - 4	<1 - 2
Filterable residue (p.p.m.)							
N=	8	24	7	7	14	11	10
$\bar{X}$	184	87	81	30	120	72	56
Range	140 - 234	55 - 140	53 - 98	25 - 38	90 - 290	45 - 90	38 - 82
Colour (Hazen units)							
N=	8	24	7		15	8	8
$\bar{X}$	55	25	36		24	28	28
Range	5 - 100	5 - 100	5 - 100		5 - 85	5 - 70	5 - 70
Turbidity (J.T.U.s)							
N=	8	25	7		15	8	8
$\bar{X}$	11.4	5.4	9.9		6.5	8.6	6.5
Range	3.1 - 16	0.5 - 22	1.2 - 20		1.0 - 35	2.3 - 19	0.9 - 15
Dissolved oxygen (mg/l)							
N=		16	10	7	17	7	8
$\bar{X}$		11.4	11.5	10.7	11.4	10	8.8
Range		9 - 14	9 - 13	9 - 12	9 - 13	8 - 12	9 - 12

Table 11. Aspects of the water chemistry of the Swan and Apsley Rivers

	Jetty road	Grange	Hardings Falls	Upper Swan	Apsley weir	Causeway	Rosedale
	1	2	3	4	5	6	7
Total nitrogen (N) p.p.m. N=		10	8		7		
$\bar{X}$		0.29	0.32		0.31		
Range		0.04 - 0.59	0.20 - 0.46		0.08 - 0.43		
Total phosphorus (P) p.p.m. N=		10	8		7		
$\bar{X}$		0.011	0.012		0.013		
Range		0.002 - 0.01	0.006 - 0.01		0.006 - 0.01		
Ca^{2+} (p.p.m.) N=	8	11	8		10	8	8
$\bar{X}$	482	335	306		343	283	250
Range	349 - 699	150 - 519	100 - 479		150 - 439	250 - 299	200 - 299
Mg^{2+} (p.p.m.) N=	8	11	8		10	8	8
$\bar{X}$	346	310	305		419	302	220
Range	49 - 576	82 - 683	82 - 453		82 - 601	165 - 412	165 - 329
Na^{2+} (p.p.m.) N=		8			8		
$\bar{X}$		551			786		
Range		479 - 609			487 - 957		
K^{+} (p.p.m.) N=		8			8		
$\bar{X}$		9.5			10.6		
Range		6.7 - 12.8			7.7 - 15.4		
Cl^{-} (p.p.m.) N=	8	11	8	1	10	8	8
$\bar{X}$	1739	523	338	254	866	526	415
Range	1269 - 2651	305 - 790	226 - 479		254 -1297	479 - 564	395 - 454

Table 11. (continued)

Quadrats measuring 3x3 metres were employed and placed every 3 metres along cross-sectional transects. The quadrats were always placed on the upstream side of the transect:



40 transects were located along the Swan and Apsley Rivers (fig 81), and a total of 439 quadrats were sampled (255 for the Swan River and 184 for the Apsley River). Percentage cover of each species was recorded for the individual quadrats, and where there was a canopy or shrub layer, % cover was recorded for the species on that plane i.e. total plot cover can be greater than 100%. Mosses and lichens were not differentiated at the species level in this study.

Except where authorities are given, nomenclature of plant species follows Curtis (1963, 1967), Curtis and Morris (1975), Willis (1970), Aston (1973), Robertson (1984), Orchard (1981, 1985), Jessop and Toelken (1986), Crowden (1986) and Wilson (1984).

4.3.2 Surveying the transects

In order to gain some idea of the height of each plot above the river channel and the cross-sectional profile of the transects, the ground along each transect was surveyed with a dumpy level and staff. Stream discharge at the time of sampling was calculated using data from the flow gauges and catchment area ratios (see chapter 3, section 3.2.3). Evidence of flood-deposited debris was also noted, and all transect sites were visited during or after a flood event in order to measure the location of the water levels up the bank. Flow frequency was thus determined for various levels at each of the transect sites. A description of the

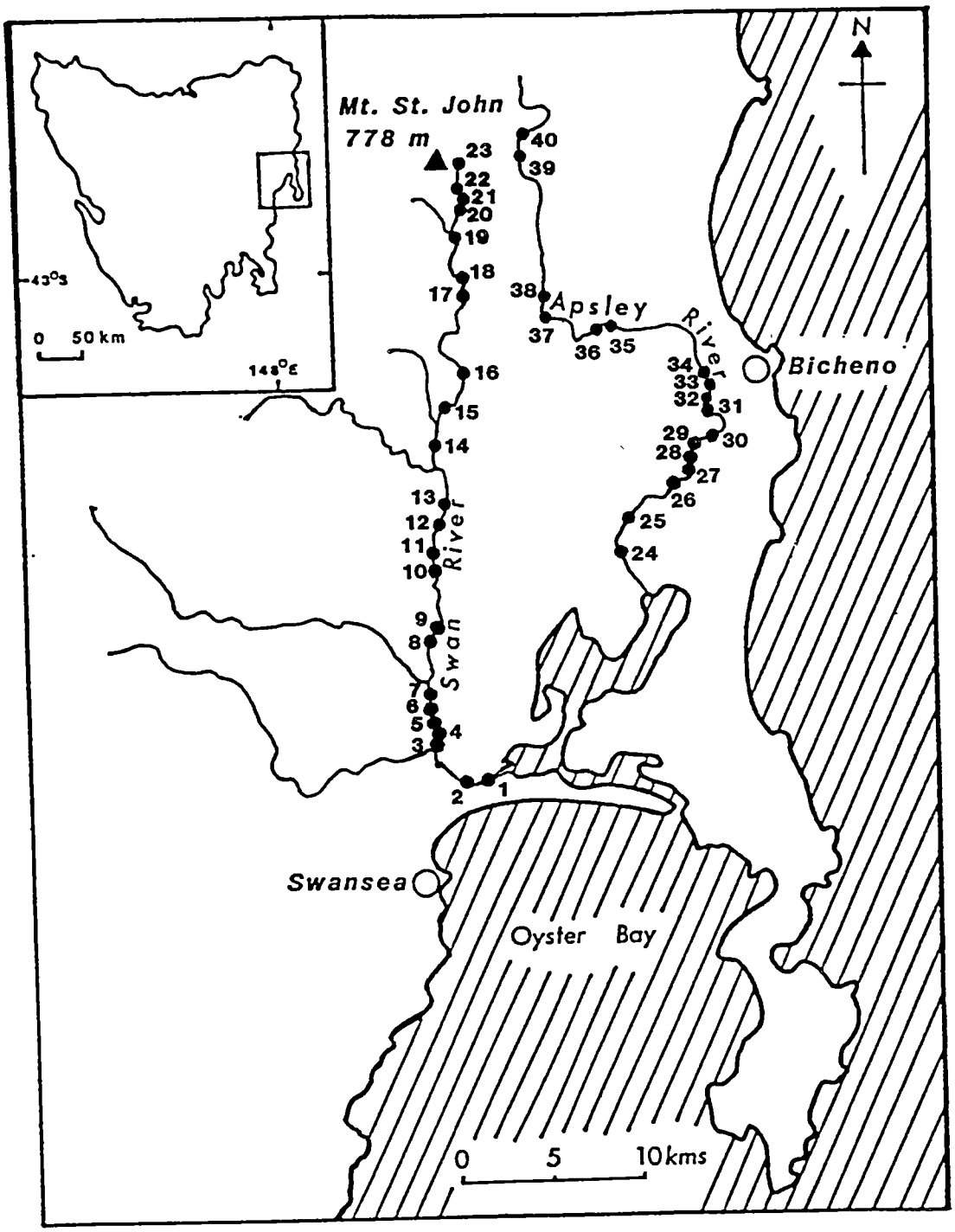


Fig. 81. The location of the 40 transects used in the riverine vegetation survey along the Swan and Apsley Rivers

substrate in each quadrat was subjectively made, each being categorized into solid rock, boulders, cobbles, pebbles, gravel, sand and silt.

Hack's (1973) index of slope and length was used to compare terrain and stream profile between the transect sites (as used by Hupp 1982). The general form is:

$$SL = (H_1 - H_2) / (\ln L_2 - \ln L_1)$$

where SL is the gradient index, H_1 and H_2 are map elevations at the two sites (using the 1: 100,000 topographic map series), and L_2 and L_1 (natural logarithms) are distances from the drainage divide to each of the sites. This index is a measure of stream power and flow resistance, with high SL values indicating high stream power. Stream power is related to the competence and the erosive capabilities of the stream (Hack 1973).

4.3.3 Data analyses

The richness of species (S) and the reciprocal of Simpson's index of diversity (N_2) (Hill 1973) were computed for each quadrat and examined in relation to the quadrat's position along the river and in relation to cross-sectional position. Analysis of variance was used to examine differences in richness and diversity per quadrat (dependent variables) with respect to longitudinal (40 transect groups) and cross-sectional (10 groups, numbered consecutively away from the river channel) location (SPSSX 1986). Pearson's product moment correlation coefficient was used to examine the correlation between richness and diversity for the 439 quadrats. Additionally, beta turnover (β_T) (Wilson and Shmida 1984) was calculated between transects along the length of each river.

By classifying the quadrats, differentiation of the riverine communities along rivers may be revealed. Alternatively, if there is a continuous trend of plant distributions as opposed to discrete groupings it will be revealed in the robustness of the classification in terms of within- and

between-type variability of assemblages. To this end, the data matrix (% cover of species x quadrats) was analysed using the polythetic divisive classification program TWINSPAN which uses two-way indicator species analysis (Hill 1979b). Detrended correspondence analysis (Hill 1979a, Gauch 1982) was used to ordinate the matrix and thereby examine the relationships between environmental parameters and plant communities.

Substrate, flow frequency, geology and gradient index (which combines altitude and distance from the drainage divide) were examined in relation to the 14-community classification for each river using four-way analysis of variance (SPSSX 1986). Data obtained for flow frequency and substrate are listed in Appendix 6, and both are divided into five groups. The data used for geology and gradient index are displayed in figures 91 and 92. Gradient indices (SL) are subdivided into three classes (0-100, 101-200, >200). The geology is classified as follows: 1= Jurassic dolerite; 2= sandstone; 3= sandstone and other sequences; 4= alluvial sand and gravel.

A critical appraisal of these analytical procedures has been provided in chapter 3, section 3.3.3.

4.4 Results

4.4.1.The vegetation

A total of 252 plant species occurred in the quadrats sampled along the Swan (201 species) and Apsley (172 species) Rivers, with 123 species common to both rivers (Appendix 5). 13 species are obligate aquatics (hydrophytes), 71 are woody shrubs or trees, and the remainder are woody creepers, herbs, grasses and helophytes. In other words, 28% of the plants sampled along the Swan and Apsley Rivers are Phanerophytes or Chamaephytes (after Raunkaier 1934), which is considerably higher than that found in other studies (Merry et al. 1981, Johnson et al. 1976). The vegetation along these rivers is most highly represented by sedges and grasses, followed by the Myrtaceae and Compositae families. This conrasts to the River Wye in Britain (Merry et al. 1981), where the Compositae and Gramineae had the most representatives, and where woody species were not prevalent (table 12).

The plants found in this survey may also be divided into facultative and obligate riverine species. Facultative riverine species occur in a variety of other habitats and are not exclusive to a river environment e.g. Banksia marginata (dry sclerophyll and coastal heaths), Potamogeton ochreatus (other wetlands). The majority of species fall into this category, with only four species being obligate riverine plants (or rheophytes, sensu Van Steenis 1981): Callistemon paludosus (endemic), Callitris oblonga (possibly obligate), Micrantheum hexandrum and Salix alba (introduced).

The central east coast of Tasmania has a relatively high occurrence of endemic (Kirkpatrick and Brown 1984) and threatened (Kirkpatrick et al. 1980) vascular plants. Endemism exceeds 15 species per 10 x 10 km grid square in this area, and 28 endemic species were recorded in the

	Wye River Merry et al. (1981)	Swan and Apsley Rivers (this study)
Total species	380	252
Family (>10 species)	%	
Compositae	10.3	
Gramineae	9.7	
Rosaceae	5.8	
Papilionaceae	4.5	
Labiatae	4.2	
Cruciferae	3.9	
Cyperaceae	3.7	
Scrophulariaceae	3.7	
Ranunculaceae	3.2	
Polygonaceae	2.9	
Juncaceae	2.9	
Salicaeae	2.6	
Others	42.6	
Family (>5 species)		%
Cyperaceae		10.7
Gramineae		9.5
Myrtaceae		7.9
Compositae		6.7
Epacridaceae		5.5
Papilionaceae		4.5
Rhamnaceae		3.6
Mimosaceae		3.6
Juncaceae		2.8
Proteaceae		2.4
Umbelliferae		2.4
Haloragaceae		2.0
Others		38.4

Table 12. The familial distribution of the aquatic and riparian plants of the Swan, Apsley and Wye Rivers (excluding mosses and lichens)

current survey. 10 species recorded in this survey are listed as rare or threatened (Kirkpatrick et al. 1980): Pultenaea selaginoides, Spyridium microphyllum, Callitris oblonga, Dodonaea ericifolia, Phebalium squameum spp. retusum, Odixia angusta, Lasiopetalum micranthum, Spyridium obovatum var. velutinum, Melaleuca pustulata, Spyridium obovatum var. obovatum.

4.4.2 Ordination and classification

The results of the ordination and classification (4-group solution) are displayed in figure 82. There is a major distinction along axis 1 between quadrats sampled at the mouth of the Swan River (groups 3 and 4) and the rest (groups 1 and 2). The division along axis 2 is generally between quadrats in the upper catchments (group 1) and those in the middle and lower reaches (group 2). However, overlapping of groups 1 and 2 along ordination axis 2 is evident, indicating that clear-cut longitudinal groupings do not exist. This is further illustrated in figure 83a-c, which represents the 14-group classification solution superimposed upon the ordination. Percentage frequency of occurrence of each species in each community is listed in Table 13.

Indicator species (and frequently occuring species) for the 14 groups are as follows:

Group 1 Beyeria viscosa
Bryophytes
(Pomaderris apetala)
(Leptospermum lanigerum)

Group 2 Melaleuca pustulata
Callistemon pallidus
Triglochin procera

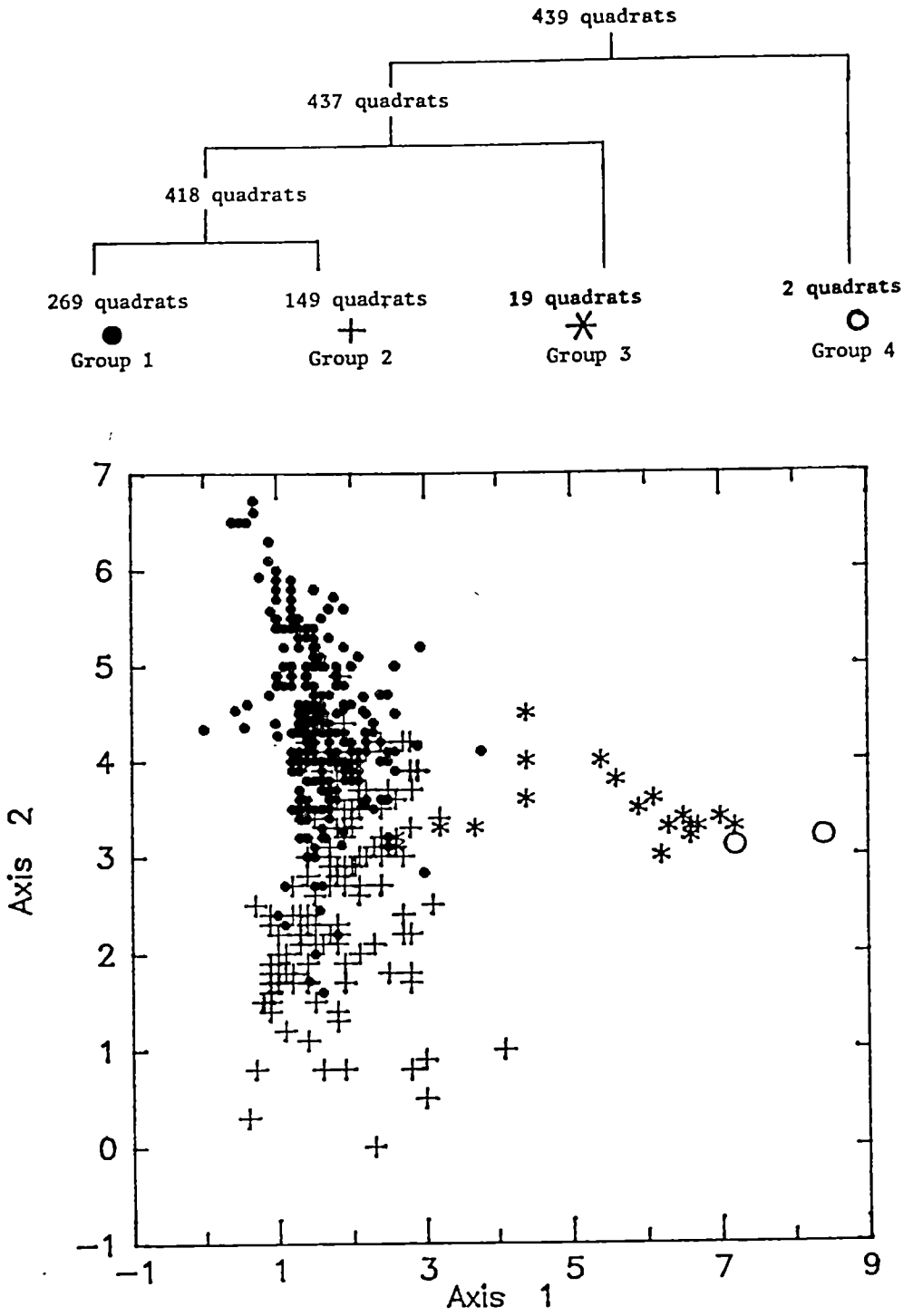


Fig. 82. Classification of riverine vegetation sampled along the Swan and Apsley Rivers. The classification groups have been superimposed upon the ordination scores of axes 1 and 2

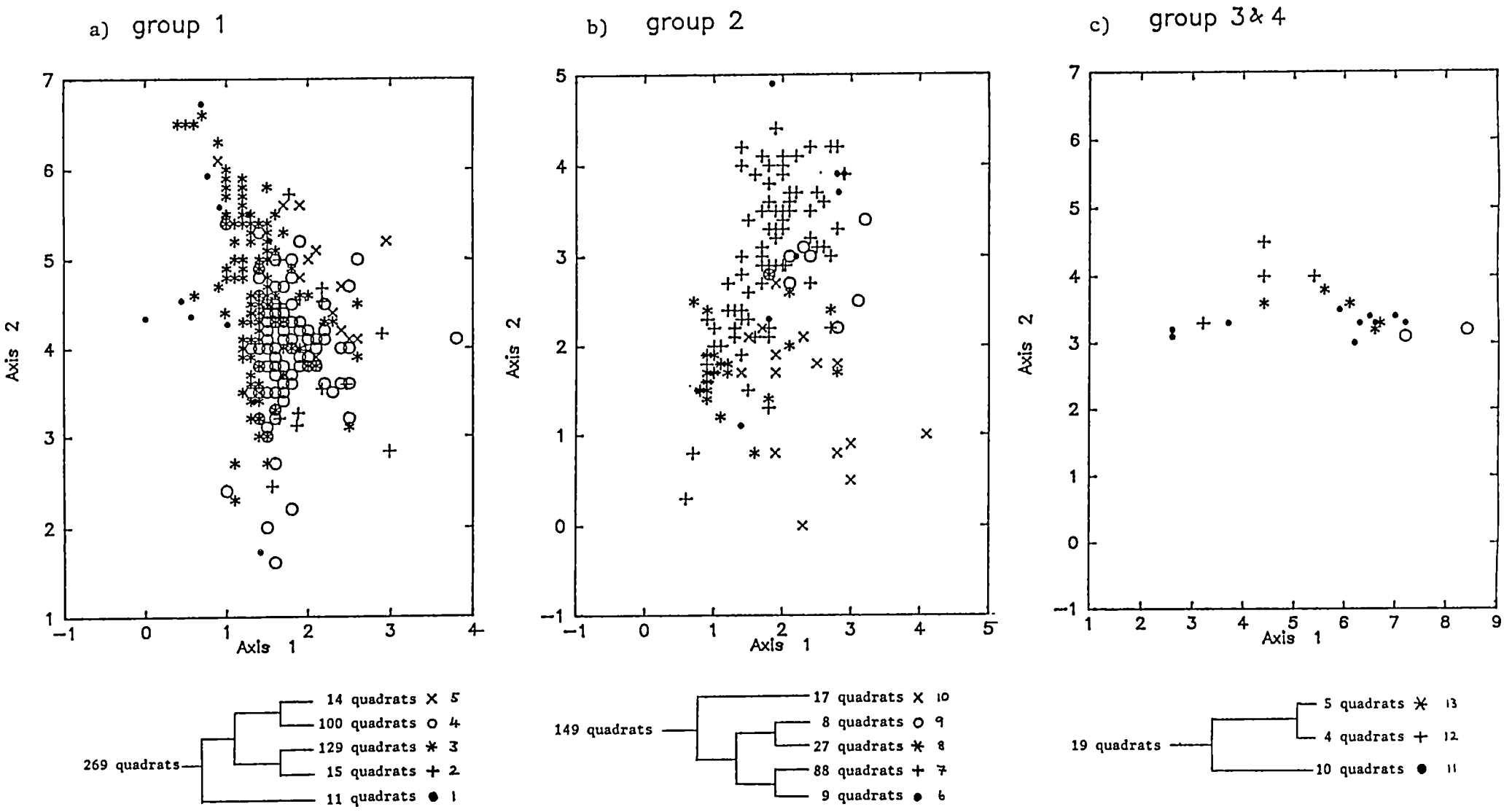


Fig. 83. Ordination of the 439 quadrats with classification (at the 14-group cut-off level) superimposed.
a) Group 1 (269 quadrats) with 5-group dendrogram below
b) Group 2 (149 quadrats) with 5-group dendrogram below
c) Groups 3 and 4 (19 and 2 quadrats) with 3-group and 1-group dendrograms

RANKED ON FREQ

	SPECIES	FREQ	(CNT)
131	pitt bico	1	9.09
111	loma tinc	1	9.09
74	euca vimi	1	9.09
22	blec nudu	1	9.09
123	olea argo	1	9.09
116	micr hexa	1	9.09
11	aotu eric	1	9.09
76	ghan gran	1	9.09
80	halo teuc	1	9.09
87	hydr java	1	9.09
168	trig proc	1	9.09
47	cyat parv	2	18.18
23	blec wats	2	18.18
13	athe mosc	2	18.18
137	poma apet	2	18.18
5	acac mucr	3	27.27
104	lept lani	6	54.55
20	beye visc	6	54.55
187	bryo phte	8	72.73

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
93	junc pall	1	6.67
125	oxal corn	1	6.67
94	junc plan	1	6.67
51	dant semi	1	6.67
60	eleo acut	1	6.67
128	para form	1	6.67
97	lepi fili	1	6.67
52	dant seta	1	6.67
65	epac impr	1	6.67
187	bryo phte	1	6.67
80	halo teuc	1	6.67
6	acac vert	1	6.67
91	junc arti	1	6.67
164	tara offi	1	6.67
171	ulex euro	1	6.67
103	lept gran	1	6.67
10	anag arve	1	6.67
192	carx spp	1	6.67
22	blec nudu	1	6.67
108	liss stri	1	6.67
78	hake liss	1	6.67
193	scir spp	1	6.67
116	micr hexa	1	6.67
117	myri pedu	1	6.67
118	myri simu	1	6.67
87	hydr java	1	6.67
136	poa poif	2	13.33
121	note ligu	2	13.33
185	tiny fern	2	13.33
158	spor virg	2	13.33
141	pter escu	2	13.33
137	poma apet	2	13.33
138	poma elli	2	13.33
1	acac axil	2	13.33
130	phra aust	3	20.00
5	acac mucr	3	20.00
153	scir flui	3	20.00
110	loma long	4	26.67
26	call poln	4	26.67
168	trig proc	4	26.67
98	lepi late	5	33.33
104	lept lani	6	40.00
114	mela pust	15	100.00

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
185	tiny fern	1	0.78
77	grev aust	1	0.78
215	acac mean	1	0.78
93	junc pall	1	0.78
130	phra aust	1	0.78
142	pult gunn	1	0.78
118	myri simu	1	0.78
151	scho flui	1	0.78
69	euca amyg	1	0.78
82	hely semi	1	0.78
97	lepi fili	1	0.78
32	cass pube	1	0.78
235	plat tria	1	0.78
88	hydr musc	1	0.78
172	unci nia	1	0.78
169	trig stri	1	0.78
96	lass micr	1	0.78
162	stip stip	1	0.78
186	lich en	1	0.78
64	epac gunn	1	0.78
189	sene cio	1	0.78
30	care fasc	1	0.78
242	spyr obco	1	0.78
237	zier arbo	1	0.78
165	tetr capi	1	0.78
70	euca glob	1	0.78
23	blec wats	1	0.78
22	blec nudu	1	0.78
240	rest moni	1	0.78
102	lept tene	1	0.78
50	dant peni	1	0.78
244	pime pauc	1	0.78
166	them aust	1	0.78
56	dodo eric	1	0.78
89	hypo radi	1	0.78
36	cirs vulg	1	0.78
90	isot fluv	1	0.78
87	hydr java	1	0.78
108	liss stri	1	0.78
152	scir cald	1	0.78
196	spyr parv	1	0.78
37	clem gent	1	0.78
67	epac pall	1	0.78
107	lila brow	1	0.78
188	fern fern	2	1.55
81	hely dend	2	1.55
18	baum tetr	2	1.55
60	eleo acut	2	1.55
211	pheb squa	2	1.55
143	pult juni	2	1.55
28	call oblo	2	1.55
163	styl gram	2	1.55
126	oxal lati	2	1.55
197	baue rubo	2	1.55

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
159	spyr micr	2	1.55
86	hove long	2	1.55
66	epac legu	2	1.55
113	mela eric	2	1.55
106	leuc coll	2	1.55
46	cyat juni	2	1.55
45	cyat diva	2	1.55
243	lept ripa	2	1.55
239	cryp amar	2	1.55
11	aotu eric	2	1.55
128	para form	2	1.55
122	nymp exig	2	1.55
212	hely bico	3	2.33
200	rest spp	3	2.33
191	junc spp	3	2.33
175	vero form	3	2.33
85	hove hete	3	2.33
145	rhag baca	3	2.33
124	olea lira	3	2.33
117	myri pedu	3	2.33
13	athe mosc	3	2.33
12	astr humi	3	2.33
54	dich repe	3	2.33
99	lepi line	3	2.33
1	acac axil	3	2.33
40	copr hert	4	3.10
38	clem micr	4	3.10
7	acae nova	4	3.10
75	exoc cupr	4	3.10
2	acac rice	4	3.10
138	poma elli	4	3.10
131	pitt bico	4	3.10
241	boro pilo	4	3.10
236	poma pili	4	3.10
43	cras sieb	4	3.10
206	hake epig	5	3.88
171	ulex euro	5	3.88
76	ghan gran	5	3.88
71	euac obli	5	3.88
15	baek ramo	5	3.88
123	olea argo	5	3.88
4	acac geni	5	3.88
41	corr refl	5	3.88
19	bedf sali	6	4.65
153	scir flui	6	4.65
72	euca ovat	6	4.65
135	poa labi	6	4.65
68	epac tasm	6	4.65
192	carx spp	7	5.43
34	casu stri	7	5.43
25	call pall	8	6.20
27	call viri	8	6.20
114	mela pust	8	6.20
21	bill long	8	6.20

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
103	lept gran	8	6.20
47	cyat parv	8	6.20
168	trig proc	9	6.98
24	burs spin	9	6.98
78	hake liss	10	7.75
3	acac deal	10	7.75
187	bryo phte	12	9.30
80	halo teuc	12	9.30
20	beye visc	12	9.30
79	hake micr	13	10.08
6	acac vert	13	10.08
65	epac impr	13	10.08
74	euca vimi	16	12.40
29	call rhom	16	12.40
33	casu litt	17	13.18
83	hibb ripp	19	14.73
111	loma tinc	20	15.50
141	pter escu	21	16.28
16	bank marg	21	16.28
110	loma long	23	17.83
105	lept scop	26	20.16
121	note ligu	34	26.36
137	poma apet	40	31.01
160	spyr obov	43	33.33
98	lepi late	50	38.76
104	lept lani	52	40.31
5	acac mucr	69	53.49
116	micr hexa	72	55.81

Group 1 Group 2 Group 3

Table 13. Percentage frequency of riverine species sampled in the 14 communities

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
156	sene jaco	1	1.00
56	dodo eric	1	1.00
224	gono tetr	1	1.00
238	stip aphy	1	1.00
223	dipl more	1	1.00
15	baek ramo	1	1.00
117	myri pedu	1	1.00
47	cyat parv	1	1.00
196	spyr parv	1	1.00
12	astr humi	1	1.00
216	copr quad	1	1.00
231	mela squa	1	1.00
146	rhag nuta	1	1.00
248	acro serr	1	1.00
249	euca pauc	1	1.00
222	acac botr	1	1.00
235	plat tria	1	1.00
112	lysi numm	1	1.00
49	dant caes	1	1.00
107	lila brow	1	1.00
103	lept gran	1	1.00
167	trif repe	1	1.00
71	euac obli	1	1.00
122	nymp exig	1	1.00
208	rume bide	1	1.00
152	scir cald	1	1.00
124	olea lira	1	1.00
86	hove long	1	1.00
214	aris pedu	1	1.00
215	acac mean	1	1.00
193	scir spp	1	1.00
142	pult gunn	1	1.00
188	fern fern	1	1.00
133	plan lanc	1	1.00
57	dodo visc	1	1.00
145	rhag baca	1	1.00
213	agro pect	1	1.00
113	mela eric	1	1.00
221	come retu	1	1.00
207	olea glan	1	1.00
91	junc arti	1	1.00
63	epil bill	1	1.00
18	baum tetr	1	1.00
247	olea ramu	2	2.00
219	dill glab	2	2.00
25	call pall	2	2.00
97	lepi fili	2	2.00
96	lass micr	2	2.00
203	pult pedu	2	2.00
85	hove hete	2	2.00
184	care appr	2	2.00
168	trig proc	2	2.00
81	hely dend	2	2.00
80	halo teuc	2	2.00

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
79	hake micr	2	2.00
153	scir flui	2	2.00
19	bedf sali	2	2.00
148	rubu frui	2	2.00
40	copr hort	2	2.00
82	hely semi	2	2.00
220	epac obtu	2	2.00
134	poa gunn	2	2.00
1	acac axil	2	2.00
130	phra aust	2	2.00
69	euca amyg	2	2.00
121	note ligu	2	2.00
31	care gaud	2	2.00
210	grat lati	2	2.00
115	mela squa	2	2.00
51	dant semi	2	2.00
246	pult stri	2	2.00
185	tiny fern	2	2.00
99	lepi line	3	3.00
191	junc spp	3	3.00
46	cyat juni	3	3.00
4	acac geni	3	3.00
162	stip stip	3	3.00
41	corr refl	3	3.00
143	pult juni	3	3.00
66	epac legu	3	3.00
21	bill long	3	3.00
111	loma tinc	3	3.00
108	liss stri	3	3.00
64	epac gunn	3	3.00
200	rest spp	4	4.00
199	gram spp	4	4.00
20	beye visc	4	4.00
192	carx spp	4	4.00
175	vero form	4	4.00
77	grev aust	4	4.00
75	exoc cupr	4	4.00
74	euca vimi	4	4.00
209	acac mela	5	5.00
187	bryo phte	5	5.00
45	cyat diva	5	5.00
34	casu stri	5	5.00
114	mela pust	6	6.00
205	odix angu	6	6.00
50	dant peni	7	7.00
160	spyr obov	7	7.00
217	fest arun	8	8.00
206	hake epig	8	8.00
164	tara offi	8	8.00
73	euca pulc	8	8.00
7	acae nova	9	9.00
16	bank marg	9	9.00
27	call viri	9	9.00
93	junc pall	10	10.00

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
54	dich repe	11	11.00
106	leuc coll	12	12.00
89	hypo radi	12	12.00
166	them aust	12	12.00
76	ghan gran	12	12.00
125	oxal corn	12	12.00
72	euca ovat	12	12.00
28	call oblo	12	12.00
33	casu litt	13	13.00
141	pter escu	14	14.00
65	epac impr	14	14.00
197	baue rubo	15	15.00
83	hibb ripp	15	15.00
171	ulex euro	15	15.00
5	acac mucr	15	15.00
3	acac deal	16	16.00
116	micr hexa	20	20.00
104	lept lani	21	21.00
68	epac tasm	22	22.00
204	mela gibb	23	23.00
135	poa labi	27	27.00
24	burs spin	33	33.00
137	poma apet	35	35.00
6	acac vert	46	46.00
98	lepi late	48	48.00
105	lept scop	52	52.00
110	loma long	63	63.00

Group 4

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
157	sene quad	1	7.14
186	lich en	1	7.14
160	spyr obov	1	7.14
97	lepi fili	1	7.14
96	lass micr	1	7.14
137	poma apet	1	7.14
214	aris pedu	1	7.14
161	spyr velu	1	7.14
65	epac impr	1	7.14
43	cras sieb	1	7.14
243	lept ripa	1	7.14
162	stip stip	1	7.14
166	them aust	1	7.14
141	pter escu	1	7.14
33	casu litt	1	7.14
241	boro pilo	1	7.14
54	dich repe	1	7.14
194	linu marg	1	7.14
103	lept scop	1	7.14
108	liss stri	1	7.14
110	loma long	1	7.14
68	epac tasm	1	7.14
30	care fasc	1	7.14
116	micr hexa	1	7.14
4	acac geni	1	7.14
126	oxal lati	1	7.14
82	hely semi	1	7.14
46	cyat juni	2	14.29
134	poa gunn	2	14.29
125	oxal corn	2	14.29
69	euca amyg	2	14.29
112	lysi numm	2	14.29
171	ulex euro	2	14.29
50	dant peni	2	14.29
146	rhag nuta	2	14.29
83	hibb ripp	4	28.57
3	acac deal	4	28.57
74	euca vimi	5	35.71
114	mela pust	5	35.71
139	spyr micr	5	35.71
99	lepi line	5	35.71
45	cyat diva	5	35.71
98	lepi late	6	42.86
135	poa labi	8	57.14

Group 5

Table 13 (continued)

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
64	holc lana	1	11.11
132	plan cori	1	11.11
147	rosa cani	1	11.11
141	pter escu	1	11.11
129	phal mino	1	11.11
74	euca vimi	2	22.22
44	crat mono	2	22.22
36	cirs vulg	2	22.22
148	rubu frui	2	22.22
110	loma long	4	44.44
134	poa gunn	5	55.56
171	ulex euro	7	77.78

Group 6

RANKED ON FREQ

	SPECIES	FREQ	(CNT)
51	dant semi	1	1.14
129	phal mino	1	1.14
66	epac legu	1	1.14
107	lila brow	1	1.14
16	bank marg	1	1.14
95	junc sand	1	1.14
186	lich en	1	1.14
190	rume xsp	1	1.14
225	hydr pter	1	1.14
182	aspe conf	1	1.14
230	lepi long	1	1.14
228	trop gunn	1	1.14
65	epac impr	1	1.14
39	coni mono	1	1.14
80	halo teuc	1	1.14
97	lepi fili	1	1.14
209	acac mela	1	1.14
206	hake epig	1	1.14
147	rosa cani	1	1.14
218	junc nodo	1	1.14
234	lotu corn	1	1.14
175	vero torn	1	1.14
58	echi ovat	1	1.14
179	aspe subs	1	1.14
96	lass micr	1	1.14
17	baum arth	1	1.14
137	poma apet	1	1.14
165	tetr capi	1	1.14
28	call oblo	1	1.14
217	fest arun	1	1.14
81	hely dend	1	1.14
180	vill reni	1	1.14
191	junc spp	1	1.14
2	acac rice	1	1.14
18	baum tetr	1	1.14
183	junc holo	1	1.14
204	mela gibb	1	1.14
132	plan cori	2	2.27
62	eleo spha	2	2.27
245	baum junc	2	2.27
1	acac axil	2	2.27
231	mela squa	2	2.27
53	desc caes	2	2.27
223	dipl more	2	2.27
103	lept gran	2	2.27
185	tiny fern	2	2.27
184	care appr	2	2.27
181	hype japo	2	2.27
91	junc arti	2	2.27
178	scho apog	2	2.27
83	hibb ripa	2	2.27
116	micr hexa	2	2.27
10	anag arve	2	2.27
156	sene jaco	2	2.27

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
153	scir flui	2	2.27
33	casu litt	2	2.27
197	baue rubo	2	2.27
64	epac gunn	3	3.41
133	plan lanc	3	3.41
229	plan vari	3	3.41
226	cent cord	3	3.41
24	burs spin	3	3.41
50	dant peni	3	3.41
46	cyat juni	3	3.41
4	acac geni	3	3.41
152	scir cald	3	3.41
150	sali alba	3	3.41
68	epac tasm	3	3.41
12	astr humi	3	3.41
138	poma elli	4	4.55
27	call viri	4	4.55
216	copr quad	4	4.55
192	carx spp	4	4.55
187	bryo phte	4	4.55
74	euca vimi	4	4.55
134	poa gunn	5	5.68
126	oxal lati	5	5.68
36	cirs vulg	5	5.68
144	ranu rivu	5	5.68
6	acac vert	6	6.82
105	lept scop	6	6.82
44	crat mono	6	6.82
164	tara offi	6	6.82
63	epil bill	7	7.95
125	oxal corn	7	7.95
114	mela pust	8	9.09
93	junc pall	8	9.09
167	trif repe	8	9.09
166	them aust	8	9.09
72	euca ovat	10	11.36
130	phra aust	11	12.50
141	pter escu	12	3.64
31	care gaud	13	14.77
54	dich repe	15	17.05
104	lept lani	15	17.05
98	lepi late	15	17.05
3	acac deal	17	19.32
5	acac mucr	17	19.32
148	rubu frui	18	20.45
171	ulex euro	19	21.59
89	hypo radi	31	35.23
113	mela eric	38	43.18
7	acae nova	47	53.41
135	poa labi	59	67.05
110	loma long	64	72.73

Group 7

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
170	typh domi	1	3.85
167	trif repe	1	3.85
185	tiny fern	1	3.85
105	lept scop	1	3.85
250	poly deci	1	3.85
168	trig proc	1	3.85
116	micr hexa	1	3.85
209	acac mela	1	3.85
187	bryo phte	1	3.85
35	char spp	1	3.85
21	bill long	1	3.85
118	myri simu	1	3.85
7	acae nova	1	3.85
30	care fasc	1	3.85
31	care gaud	1	3.85
226	cent cord	1	3.85
252	typh orie	1	3.85
217	fest arun	1	3.85
60	eleo acut	1	3.85
234	lotu corn	1	3.85
20	beye visc	1	3.85
121	note ligu	1	3.85
64	epac gunn	1	3.85
133	plan lanc	1	3.85
76	ghan gran	1	3.85
137	poma apet	1	3.85
84	holc lana	1	3.85
148	rubu frui	1	3.85
150	sali alba	1	3.85
152	scir cald	1	3.85
164	tara offi	1	3.85
144	ranu rivu	2	7.69
130	phra aust	2	7.69
91	junc arti	2	7.69
225	hydr pter	2	7.69
192	carx spp	2	7.69
9	agro stol	2	7.69
135	poa labi	3	11.54
62	eleo spha	3	11.54
184	care appr	3	11.54
180	vill reni	3	11.54
171	ulex euro	3	11.54
169	trig stri	3	11.54
6	acac vert	3	11.54
93	junc pall	4	15.38
110	loma long	4	15.38
104	lept lani	4	15.38
5	acac mucr	4	15.38
113	mela eric	24	92.31

Group 8

RANKED ON FREQ

	SPECIES	FREQ	(PCNT)
132	plan cori	1	12.50
117	myri pedu	1	12.50
93	junc pall	1	12.50
61	eleo grac	1	12.50
171	ulex euro	1	12.50
174	utri dich	1	12.50
184	care appr	1	12.50
5	acac mucr	1	12.50
153	scir flui	1	12.50
150	sali alba	1	12.50
53	desc caes	1	12.50
116	micr hexa	1	12.50
60	eleo acut	2	25.00
36	cirs vulg	2	25.00
49	dant caes	2	25.00
164	tara offi	2	25.00
10	anag arve	2	25.00
135	poa labi	2	25.00
39	coni mono	2	25.00
167	trif repe	2	25.00
130	phra aust	3	37.50
114	mela pust	4	50.00
104	lept lani	5	62.50
91	junc arti	6	75.00

Group 9

Table 13 (continued)

RANKED ON FREQ

SPECIES	FREQ	(PCNT)
135 poa labi	1	5.88
6 acac vert	1	5.88
22 blec nudu	1	5.88
139 pota pect	1	5.88
197 baue rubo	1	5.88
90 isot fluv	1	5.88
173 utri aust	1	5.88
233 poly hydr	1	5.88
30 care fasc	1	5.88
232 mont aust	1	5.88
48 cype gunn	1	5 88
227 lotu pedu	1	5.88
114 mela pust	1	5 88
107 lila brow	1	5.88
184 care appr	1	5.88
112 lysi numm	1	5.88
234 lotu corn	1	5.88
170 typh domi	1	5.88
63 epil bill	1	5 88
251 pota ochr	2	11.76
59 elat grat	2	11.76
93 junc pall	2	11.76
130 phra aust	2	11.76
120 nite spp	2	11.76
250 poly deci	2	11.76
117 myri pedu	2	11.76
35 char spp	2	11.76
195 lepi aust	2	11.76
183 junc holo	2	11.76
113 mela eric	2	11.76
17 baum arth	2	11.76
144 ranu rivu	3	17.65
119 myri sals	3	17.65
225 hydr pter	3	17.65
91 junc arti	4	23.53
140 pota perf	5	29.41
180 vill reni	5	29.41
153 scir flui	6	35.29
104 lept lani	6	35.29
60 eleo acut	7	41.18
118 myri simu	8	47.06
168 trig proc	9	52 94
62 eleo spha	10	58.82

Group 10

RANKED ON FREQ

SPECIES	FREQ	(PCNT)
202 cent nini	1	10.00
200 rest spp	1	10.00
137 poma apet	1	10.00
169 trig stri	1	10.00
201 cras helm	1	10.00
198 ranu ranu	1	10.00
110 loma long	1	10.00
155 sell radi	1	10.00
6 acac vert	1	10.00
109 lobe alat	1	10 00
14 atri cine	1	10.00
114 mela pust	1	10.00
149 rupp mega	1	10.00
107 lila brow	1	10.00
17 baum arth	1	10.00
8 agro scab	2	20.00
42 cotu long	2	20.00
101 lept brow	2	20.00
36 cirs vulg	2	20.00
119 myri sals	3	30.00
177 rost nuel	3	30.00
139 pota pect	3	30.00
133 plan lanc	3	30.00
130 phra aust	3	30.00
132 plan cori	4	40.00
55 dist dist	4	40 00
127 pach arbu	5	50.00
135 poa labi	6	60.00
92 junc krau	6	60 00

Group 11

RANKED ON FREQ

SPECIES	FREQ	(PCNT)
125 oxal corn	1	25.00
164 tara offi	1	25.00
92 junc krau	1	25.00
176 vero grac	1	25.00
135 poa labi	1	25.00
98 lepi late	1	25.00
108 liss stri	1	25.00
141 pter escu	3	75.00
171 ulex euro	3	75.00
162 stip stip	3	75.00
55 dist dist	4	100.00

Group 12

RANKED ON FREQ

SPECIES	FREQ	(PCNT)
171 ulex euro	1	20.00
6 acac vert	1	20.00
114 mela pust	1	20.00
94 junc plan	1	20.00
162 stip stip	1	20.00
154 scir nodo	1	20.00
127 pach arbu	2	40.00
199 gram spp	2	40.00
89 hypo radi	2	40.00
132 plan cori	3	60.00
92 junc krau	4	80.00
55 dist dist	5	100.00

Group 13

RANKED ON FREQ

SPECIES	FREQ	(PCNT)
127 pach arbu	1	50.00
92 junc krau	1	50.00
169 trig stri	1	50 00
201 cras helm	1	50.00
202 cent nini	1	50.00
149 rupp mega	2	100.00

Group 14

Table 13 (continued)

Group 3 Micrantheum hexandrum
Acacia mucronata
Spyridium obovatum var. obovatum
Leptospermum scoparium

Group 4 Lomandra longifolia
Acacia verticillata
Leptospermum scoparium
(Bursaria spinosa)

Group 5 Spyridium microphyllum
Lepidosperma laterale
(Hibbertia riparia)

Group 6 Ulex europaeus
Poa gunnii

Group 7 Poa labillardieri
Aceana novae-zelandicae
Melaleuca ericifolia
Hypochaeris radicata
Lomandra longifolia

Group 8 Melaleuca ericifolia

Group 9 Juncus articulatus
Melaleuca pustulata
Leptospermum lanigerum
Phragmites australis
Anagallis arvensis spp. arvensis
Cirsium vulgare

Group 10 Eleocharis sphacelata
Myriophyllum simulans
Triglochin procera

Group 11 Poa labillardieri
Myriophyllum salsugineum

Group 12 Pteridium esculentum
(Distichlis distichophylla)
(Stipa sp.)

Group 13 Juncus kraussii
Plantago coronopus
(Distichlis distichophylla)

Group 14 Ruppia megacarpa

The 14 groups have been mapped along the transects for the Swan and Apsley Rivers (figures 84 and 85 respectively). The flat lower reaches of both rivers have a preponderance of communities dominated by Melaleuca ericifolia (swamp paper-bark). Quadrats in group 8 are almost monospecifically M. ericifolia e.g. transect 24 on the Apsley River, which cuts across the Apsley marshes. Group 7 quadrats are not as permanently inundated as group 8 quadrats, and this is demonstrated by the occurrence of small herbs such as Acaena novae-zelandiae and the grass Poa labillardieri as well as M. ericifolia. Where there is a sufficiently deep and permanent water body, aquatic herbfield, or communities of hydrophytes occur (group 10). These are found in the main channel of the Swan and Apsley Rivers e.g. transects 7 and 25, and in inundated backwaters e.g. transects 8 and 24. Group 9 quadrats are found in areas that are sufficiently inundated to support Juncus articulatus and Phragmites australis (emergent aquatics), but sufficiently dry to support Leptospermum lanigerum and Melaleuca pustulata (both woody species) i.e. sites that are periodically inundated on a well defined bank e.g transect 8. Group 9 community is exclusive to the Swan River, which probably reflects the restriction of M. pustulata to this catchment.

Group 6 communities are dominated by Ulex europaeus (gorse), which is an introduced species that has successfully competed with the native flora along many rivers. This is

Group 12 Pteridium esculentum
(Distichlis distichophylla)
(Stipa sp.)

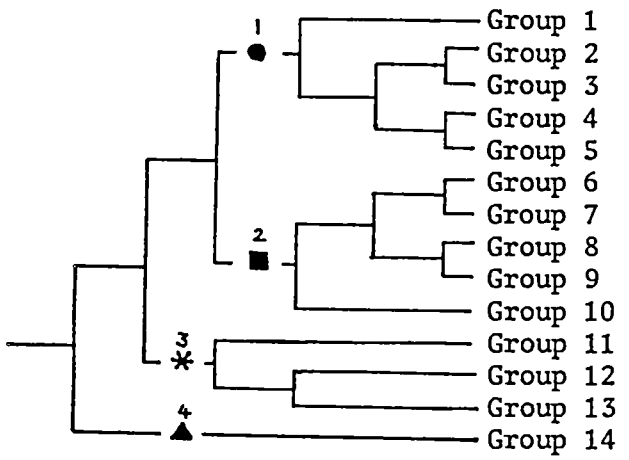
Group 13 Juncus kraussii
Plantago coronopus
(Distichlis distichophylla)

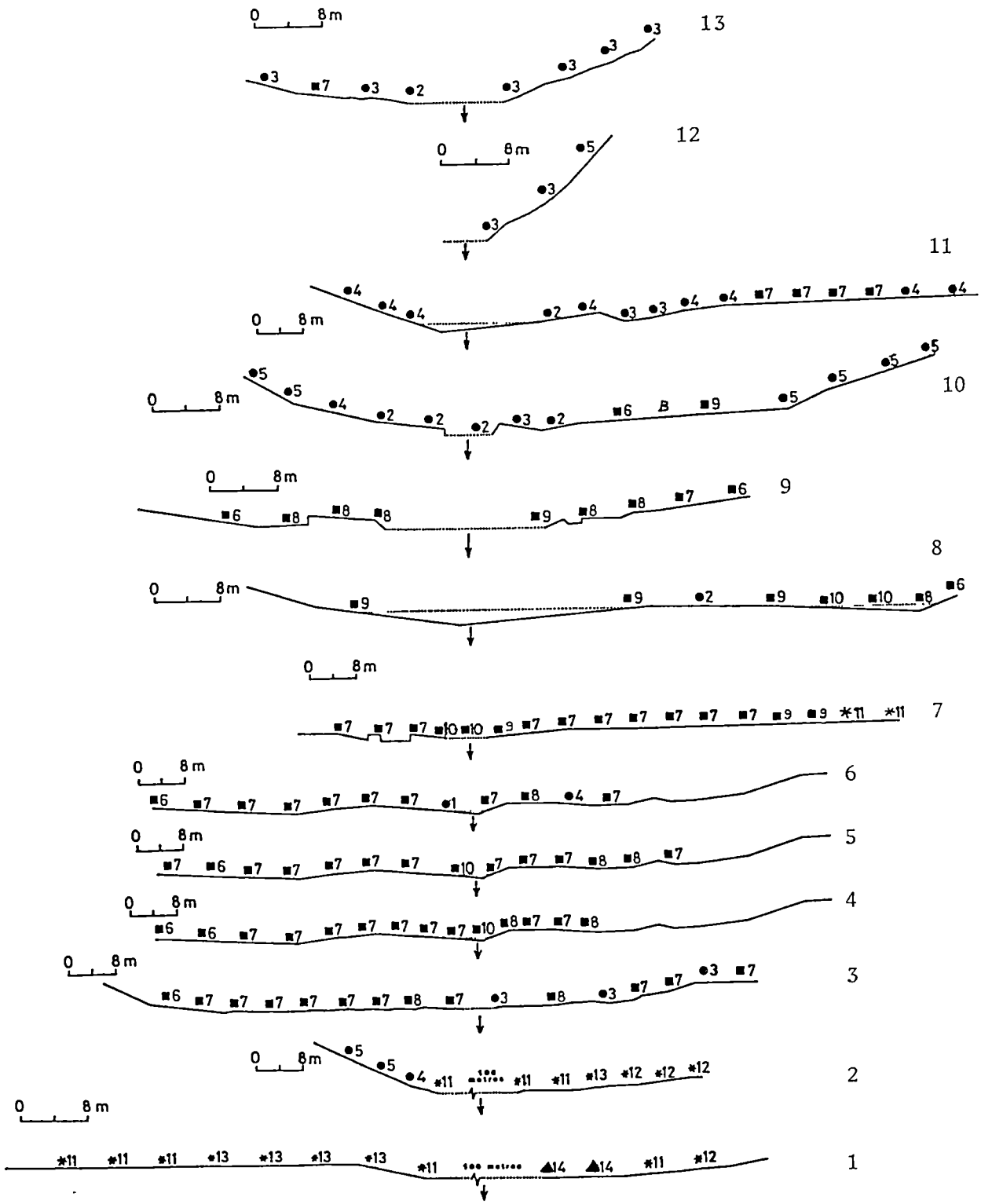
Group 14 Ruppia megacarpa

The 14 groups have been mapped along the transects for the Swan and Apsley Rivers (figures 84 and 85 respectively). The flat lower reaches of both rivers have a preponderance of communities dominated by Melaleuca ericifolia (swamp paper-bark). Quadrats in group 8 are almost monospecifically M. ericifolia e.g. transect 24 on the Apsley River, which cuts across the Apsley marshes. Group 7 quadrats are not as permanently inundated as group 8 quadrats, and this is demonstrated by the occurrence of small herbs such as Acaena novae-zelandiae and the grass Poa labillardieri as well as M. ericifolia. Where there is a sufficiently deep and permanent water body, aquatic herbfield, or communities of hydrophytes occur (group 10). These are found in the main channel of the Swan and Apsley Rivers e.g. transects 7 and 25, and in inundated backwaters e.g. transects 8 and 24. Group 9 quadrats are found in areas that are sufficiently inundated to support Juncus articulatus and Phragmites australis (emergent aquatics), but sufficiently dry to support Leptospermum lanigerum and Melaleuca pustulata (both woody species) i.e. sites that are periodically inundated on a well defined bank e.g transect 8. Group 9 community is exclusive to the Swan River, which probably reflects the restriction of M. pustulata to this catchment.

Group 6 communities are dominated by Ulex europaeus (gorse), which is an introduced species that has successfully competed with the native flora along many rivers. This is

Fig. 84. Cross-sectional transects (1-23) for the Swan River showing the location of quadrats on each. Groups derived from the TWINSPAN classification (at the 4-group and 14-group cut-off levels) have been superimposed onto the quadrats. B = quadrat with no vegetation. Vertical and horizontal scales are the same

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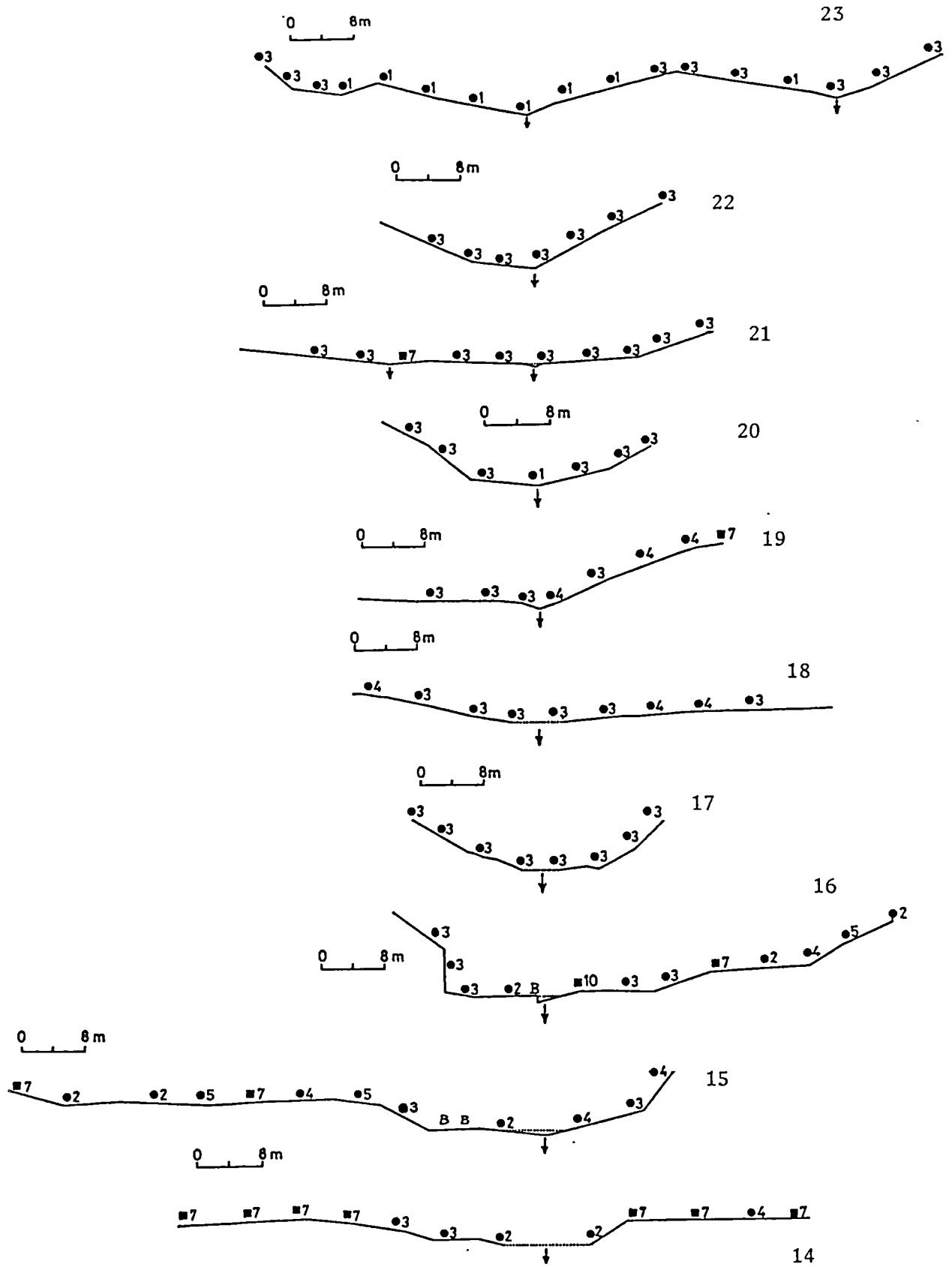
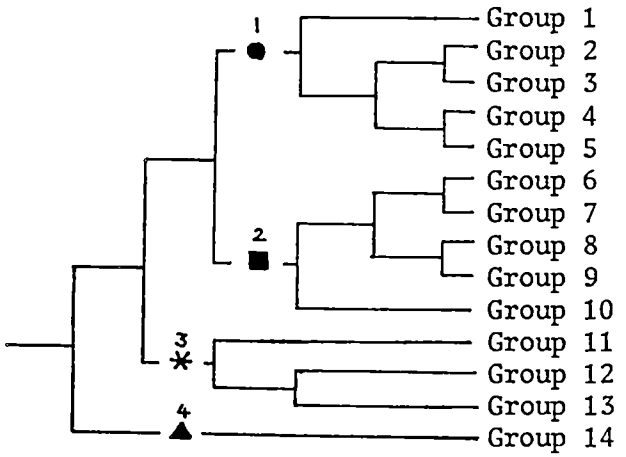
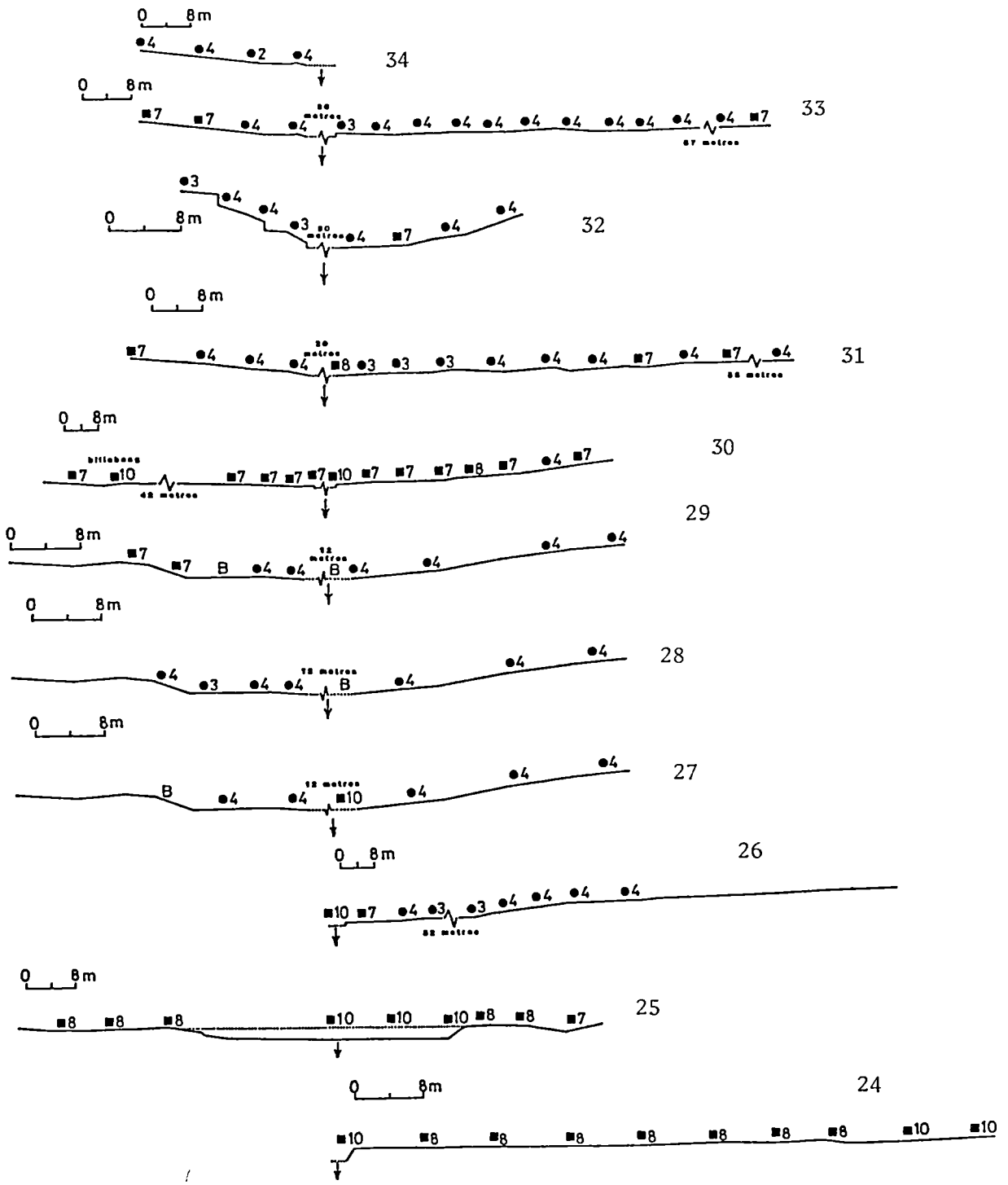


Fig. 84. (continued)

Fig. 85. Cross-sectional transects (24-40) for the Apsley River showing the location of quadrats on each. Groups derived from the TWINSPAN classification (at the 4-group and 14-group cut-off levels) have been superimposed onto the quadrats. B = quadrat with no vegetation. Vertical and horizontal scales are the same

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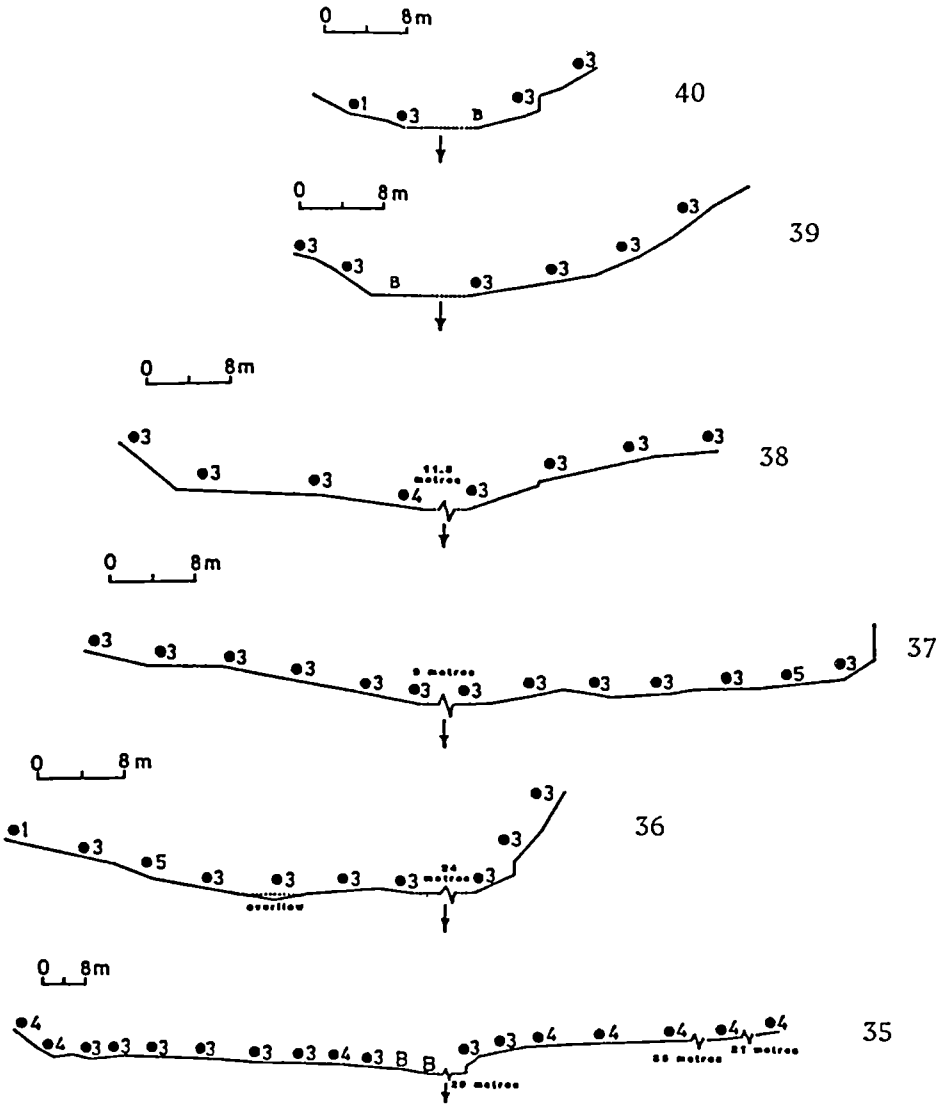


Fig. 85. (continued)

especially the case for rivers cutting through agricultural areas e.g transects 5, 6 and 10 on the Swan River.

Beyeria viscosa is a small tree characteristic of gully communities in the east of the state, and together with bryophytes is indicative of group 1 quadrats. This community is found in the headwaters of the Swan and Apsley Rivers, with some patches at lower altitudes e.g. transects 20 and 6. Also in the headwaters are communities dominated by Micrantheum hexandrum and Spyridium obovatum var. obovatum (woody species) (group 3) e.g. transects 22, 21, 40 and 39. Group 2 communities characterize sites in or by the river channel for mid- and upper-stream localities on the Swan River e.g. transects 10, 11 and 13. These quadrats are dominated by Melaleuca pustulata and Callistemon pallidus (woody species), with Triglochin procera if the quadrat covers part of the stream. The aquatic hydrophyte Triglochin procera (morphological form D, after Robb and Ladiges 1981) appears characteristic of upper channel sites.

Group 4 communities are characteristic of dry but periodically inundated environments on the middle reaches of both rivers. Lomandra longifolia and Acacia verticillata (woody species) are found in this group, together with several rare and threatened species e.g. Callitris oblonga, Odixia angusta, Pultenaea selaginoides. Spyridium microphyllum, which is rare and endemic, is an indicator species of group 5 communities, together with Lepidosperma laterale. Again this community is characteristic of dry but periodically flooded parts of the river channel. Both groups 4 and 5 tend to be exclusive to dolerite environments, where there are poor soils and little moisture retention.

Groups 11 and 14 are found at the tidal mouth of the Swan River, where the aquatic hydrophytes Ruppia megacarpa and Myriophyllum salsugineum are found. In the flat marshy areas bordering the river, species such as Juncus kraussii, Sclerostegia arbuscula and Selliera radicans grow, as well as Melaleuca pustulata.

The middle sections of both rivers support a mosaic of upper and lower catchment communities e.g. Transects 10, 11, 14, 31. Where there are flat, frequently inundated floodplains on the middle sections of the rivers, lower catchment communities prevail e.g. transect 30 on the middle Apsley River. Interestingly, the lower catchment communities (■ figures 84 and 85) tend to colonize away from the river channel on the mid-river transects, while the upper catchment communities (● figures 84 and 85) colonize sites closer to the channel. Van Steenis (1981) comments on this 'telescoping' distribution of high altitude plants to lower altitudes along water courses, although whether this is due to water dispersal or the microclimate of the stream course is debatable.

4.4.3 Community structure

Species diversity (N_2) and richness are plotted for each quadrat along the Swan and Apsley Rivers in figures 86 to 89. Richness (range 0 to 20) and diversity (range 0 to 1) differ significantly along the lengths of the rivers ($p < 0.001$), with the middle reaches having the highest richness and greatest polydominance. There is no significant variation in diversity and richness along each transect:

	Source of variation	
Variable	Longitudinal sites (N=40)	Cross-sectional sites (N=10)
Richness (S)	$F = 3.82$	$F = 0.47$
	$p < 0.001$	N.S.
Diversity (N_2)	$F = 3.29$	$F = 0.58$
	$p < 0.001$	N.S.

Richness and diversity are significantly correlated ($r = 0.741$, $p < 0.001$), but there appears to be little distinction between the 4-group classification (fig 90). However, quadrats with high diversity (>0.8) and high

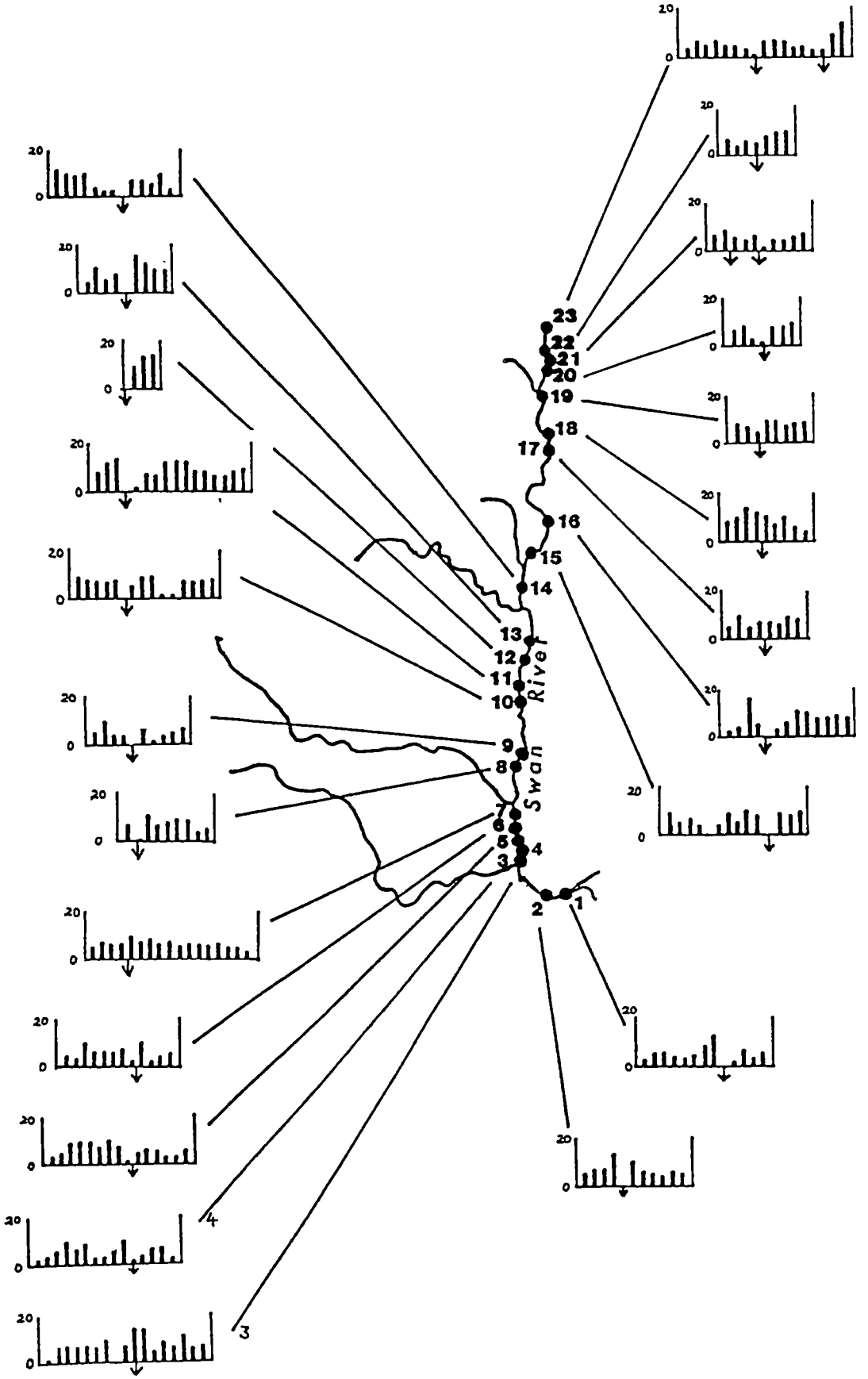


Fig. 86. Species richness (S) plotted along each transect for the Swan River. Arrows show the location of the river channel. Gaps along the transects indicate quadrats with no vegetation

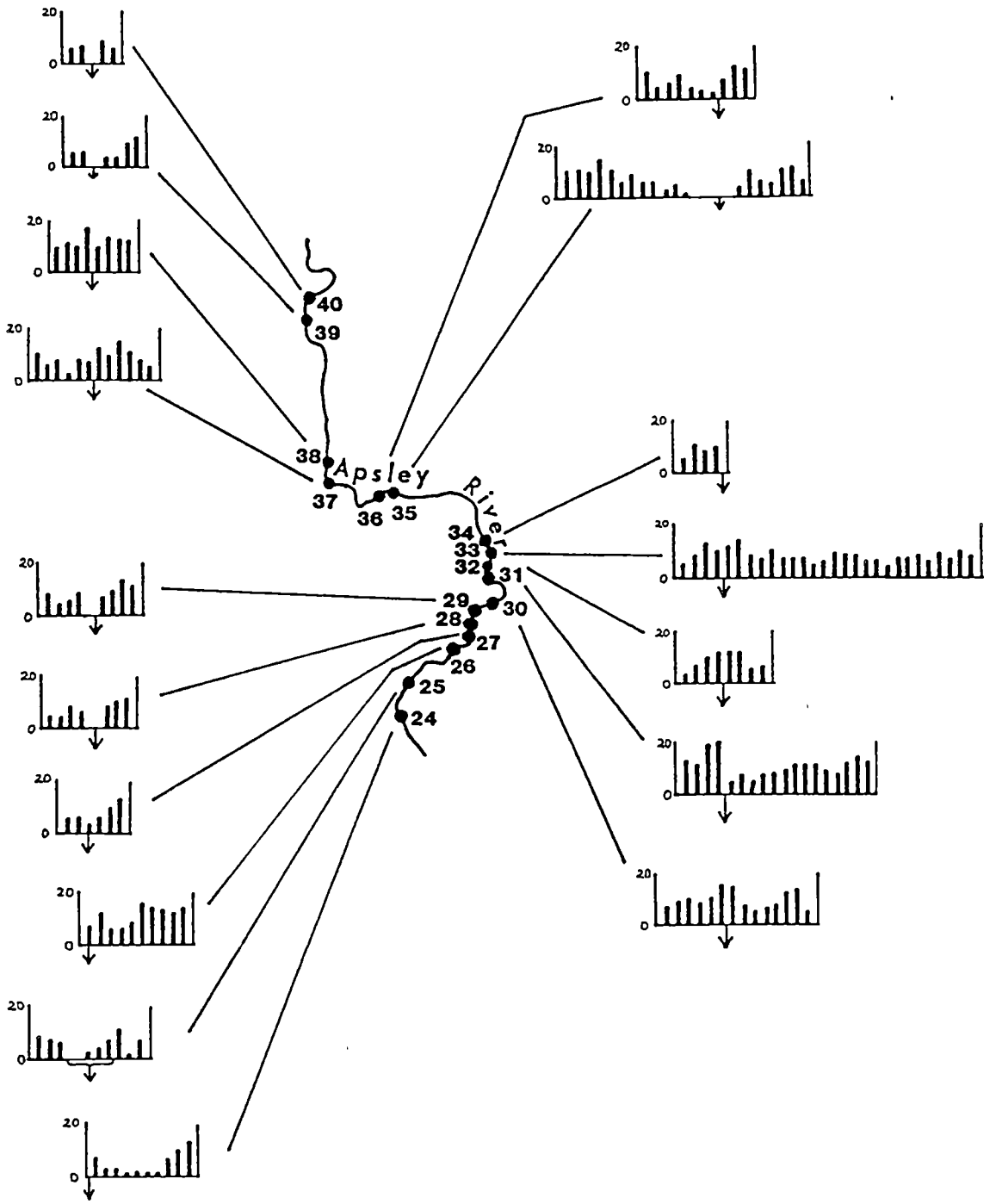


Fig. 87. Species richness (S) plotted along each transect for the Apsley River. Arrows show the location of the river channel. Gaps along the transects indicate quadrats with no vegetation

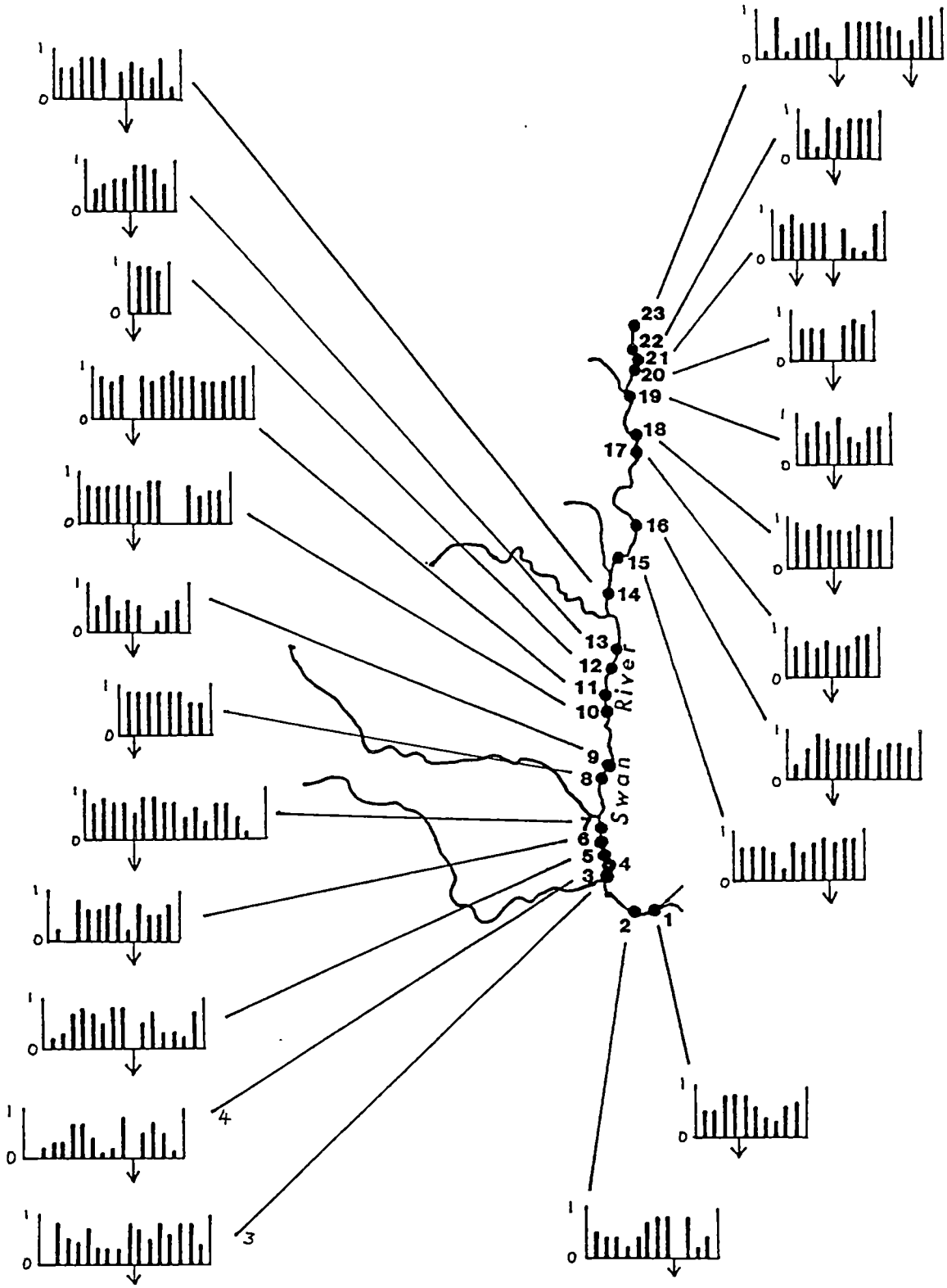


Fig. 88. Species diversity (N_2) plotted along each transect for the Swan River. Arrows show the location of the river channel. Gaps along the transects indicate quadrats with no vegetation

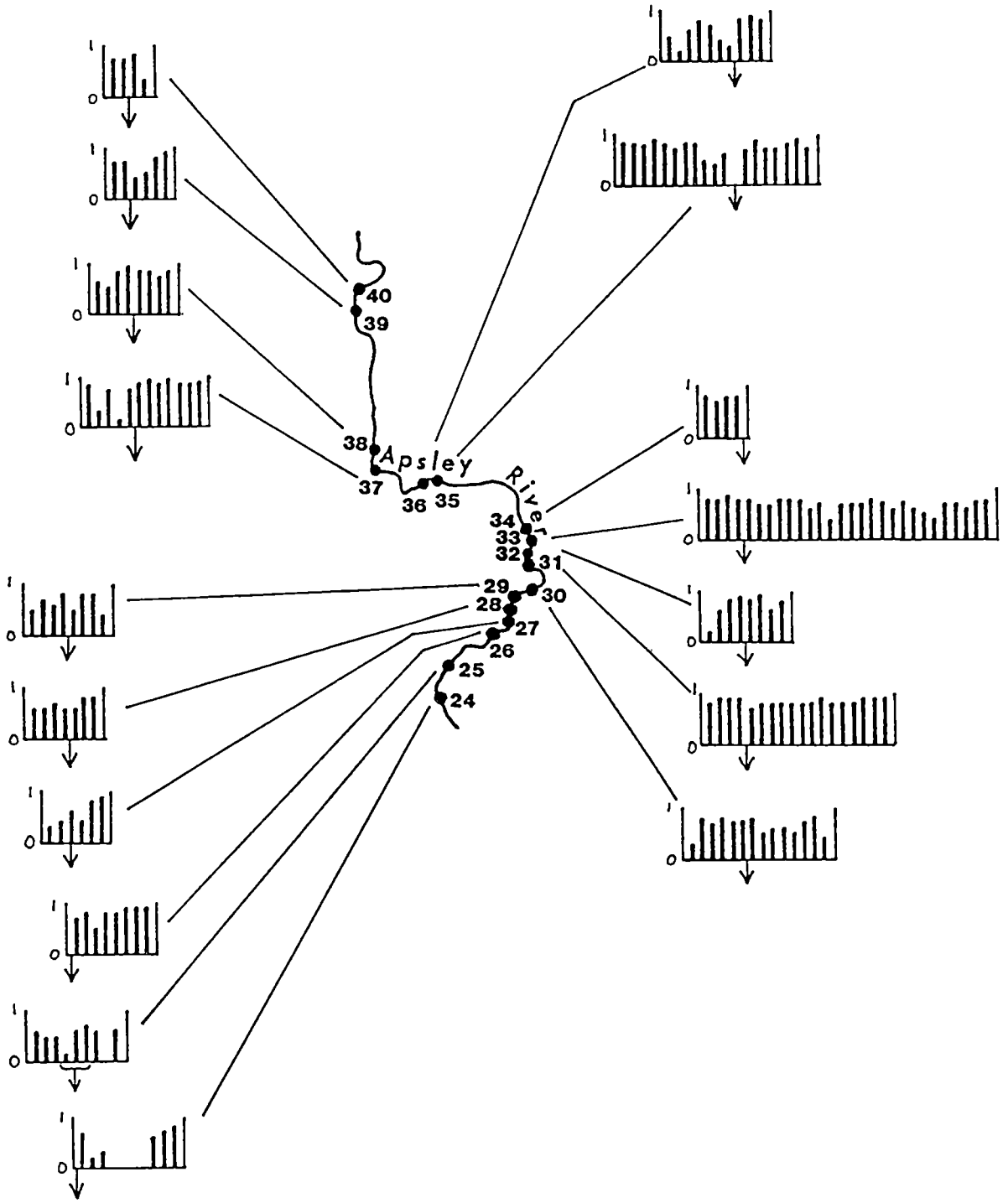


Fig. 89. Species diversity (N_2) plotted along each transect for the Apsley River. Arrows show the location of the river channel. Gaps along the transects indicate quadrats with no vegetation

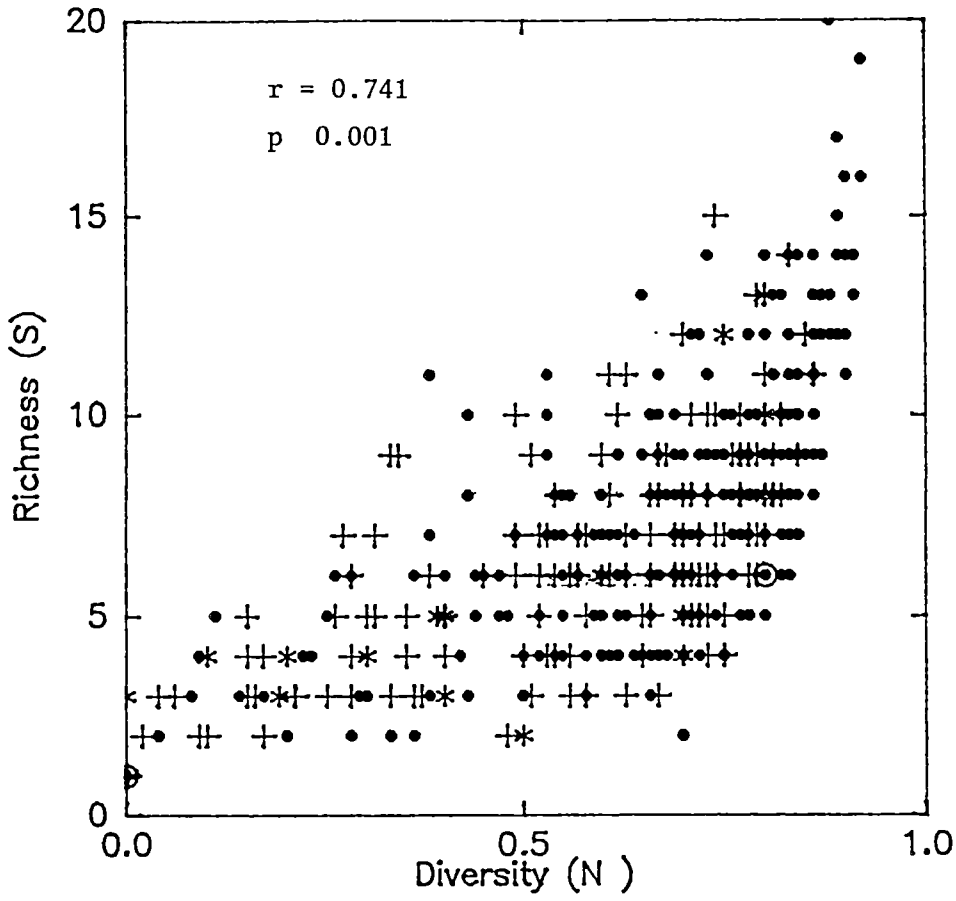


Fig. 90. Pearson product moment correlation of species richness plotted against diversity for the 439 quadrats. The 4-group classification is superimposed

richness (>12) are located on the middle reaches of both rivers, and communities at the mouth of the Swan River (*) have low richness and species dominance.

Longitudinal variation in beta turnover and species richness per transect is illustrated in figures 91 and 92. Turnover is relatively high throughout the length of the rivers, and especially transects 9, 13 and 16 along the Swan River, and transects 30, 29 and 25 along the Apsley River. Transect 30 experiences a complete species shift.

4.4.4 Environmental variables

The geology and gradient index (SL) for each transect are displayed in figures 91 and 92. Substrate and flow frequency of each plot are listed in Appendix 6. Figure 49 (chapter 3) and Appendix 3 displays frequencies of particular discharges for the Swan and Apsley Rivers. Flows with a 6-month recurrence interval measure 51.2 cumecs for the Apsley River u/s of the Coles Bay Road and 74.0 cumecs for the Swan River at the Grange.

Results of the four-way analysis of variance for each river are listed in table 14, demonstrating that longitudinal variation in plant communities (i.e. using geology and SL for each transect) along the Swan River is due to geology ($p < 0.001$), while altitude and distance from the divide (SL) is not significant. For the Apsley River, both geology and SL account for the longitudinal variation in plant communities.

Cross-sectional variation of plant communities along each transect is due to differences in substrate and flow frequency. Substrate is more important for the Swan River ($F=10.99$) than flow frequency ($F=5.3$), and the reverse is true for the Apsley River.

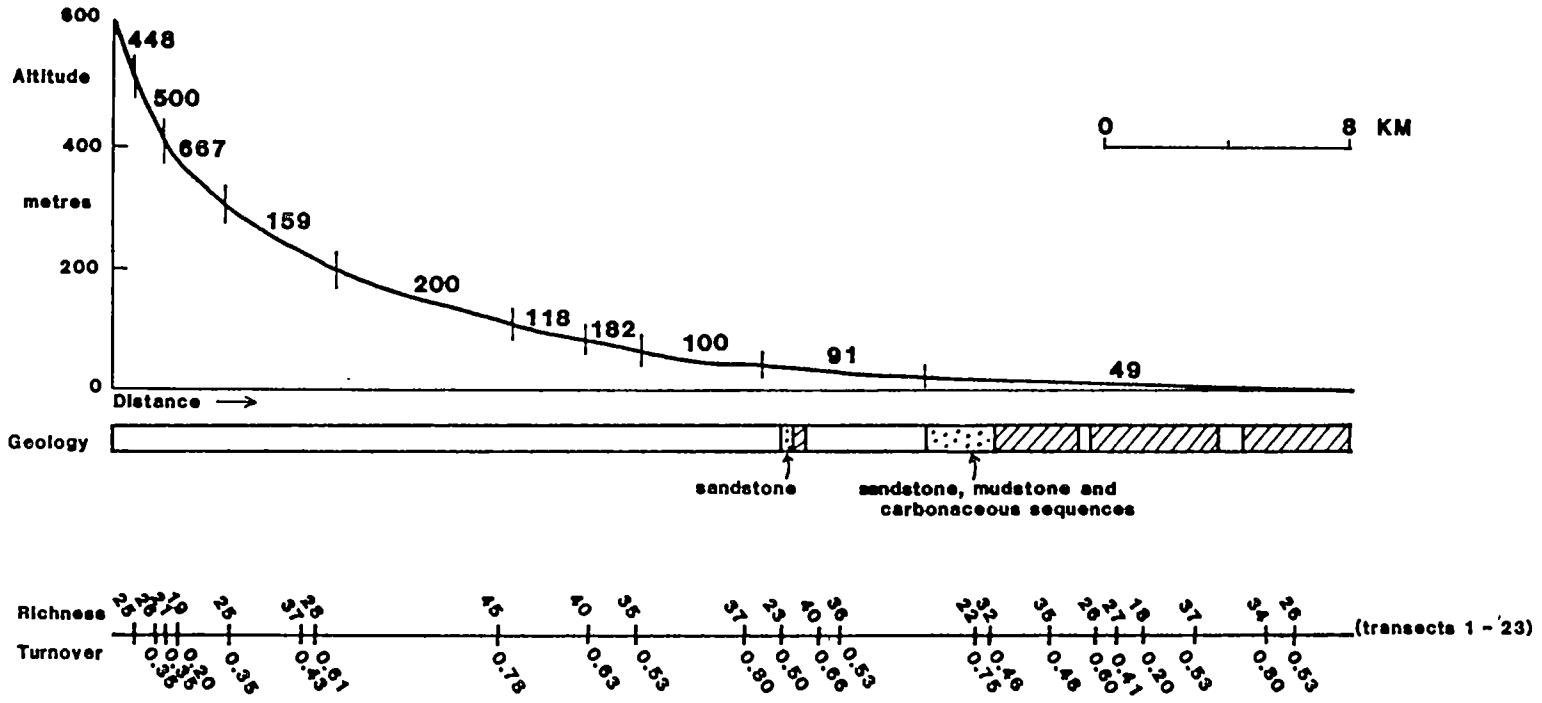


Fig. 91. Stream profile, slope index values (SL) and geology for the Swan River. Species richness and beta turnover are plotted (below) for each transect.

□ = Jurassic dolerite; ▨ = alluvial sands and gravel

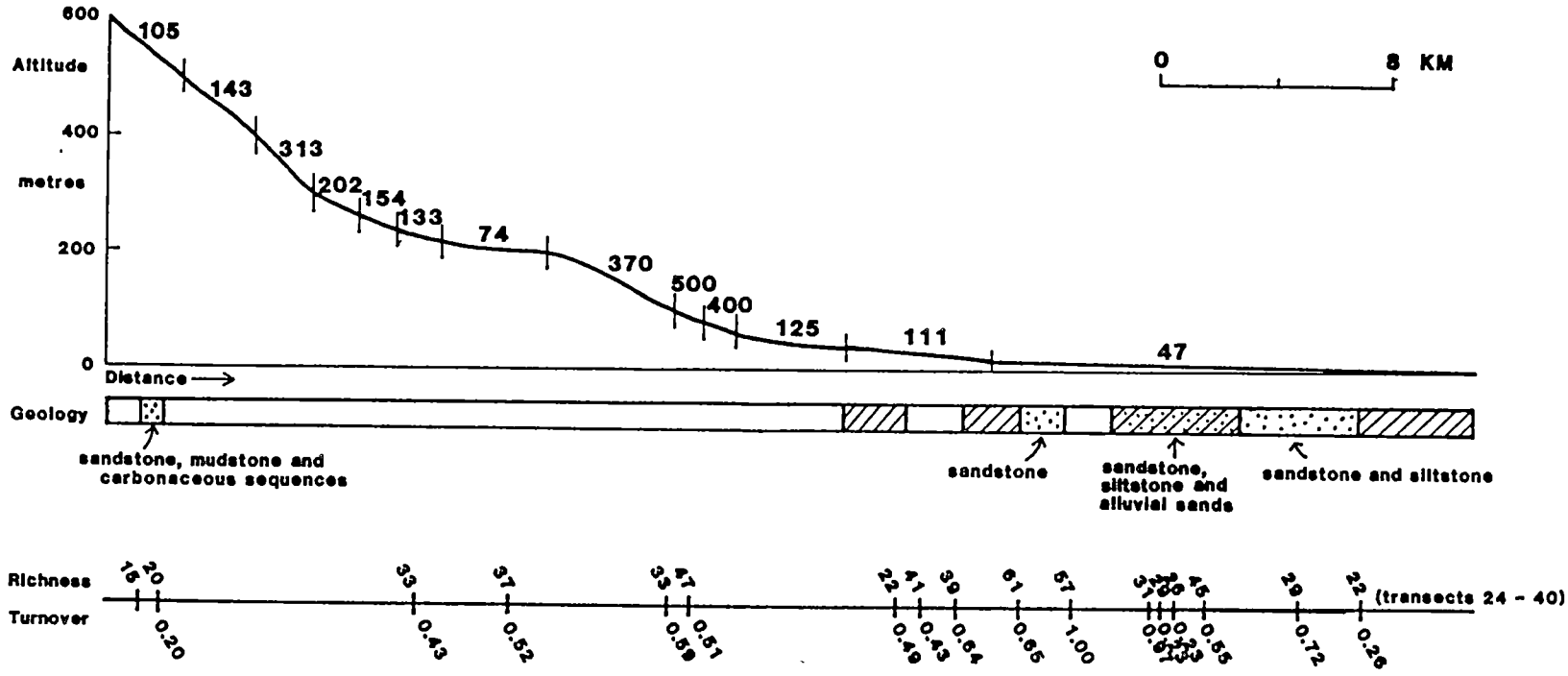


Fig. 92. Stream profile, slope index values (SL) and geology for the Apsley River. Species richness and beta turnover are plotted (below) for each transect.

▭ = Jurassic dolerite; ▨ = alluvial sands and gravel

	Source of variation			
Variable	Substrate N = 5	Flow N = 5	Geology N = 4	S.L. N = 3
Swan Classification	10.99 p<0.001	5.3 p<0.001	20.23 p<0.001	0.38 N.S.
Apsley Classification	7.13 p<0.001	21.32 p<0.001	6.71 p<0.001	12.79 p<0.001

Table 14. F-values and their associated levels of significance for the 4-way ANOVAs on the riverine classification for the Swan and Apsley Rivers

The major substrate types and flow frequencies for the 14 communities are as follows:

Group 1 Beyeria - bryophyte
< 1 in 6 month to 1 in 12 month flow
Solid rock and boulders

Group 2 Melaleuca pustulata - Callistemon - Triglochin
1 in 12 month to 1 in 10 year flow (also found in permanent to 1 in 6 month category)
Sand and silt; consolidated and unconsolidated cobble and pebble

Group 3 Micrantheum - Leptospermum - Acacia mucronata-Spyridium
Unconsolidated cobble and pebble (middle catchment)
Boulders (upper catchment)
Also some sites in categories 1, 4 and 5
< 1 in 6 month to 1 in 12 month flow (also categories 1 and 2 - see appendix 6)

Group 4 Lomandra - Leptospermum scoparium - Acacia verticillata
All substrate categories except unconsolidated cobble and pebble. Tendency towards sand and silt in lower catchment sites
1 in 12 month to 1 in 10 year flow (upper catchment)
< 1 in 6 month to 1 in 12 month flow (lower catchment)

Group 5 Spyridium microphyllum - Lepidosperma laterale
Consolidated cobble and pebble (also category 2)
1 in 6 month to 1 in 10 year flow

Group 6 Ulex - Poa gunnii
Consolidated and unconsolidated cobble and pebble
< 1 in 6 month to 1 in 12 month flow

Group 7 Poa labillardieri - Acaena - Melaleuca - Lomandra
Sand and silt; consolidated and unconsolidated cobble and pebble
< 1 in 6 month to 1 in 12 month flow

Group 8 Melaleuca ericifolia
Sand and silt (also category 3)
Permanent to 1 in 6 month flow (also category 2)

Group 9 Juncus articulatus - Melaleuca - Leptospermum - Phragmites
Sand and silt; consolidated and unconsolidated pebble and cobble
Permanent to 1 in 22 month flow

Group 10 Eleocharis - Myriophyllum - Triglochin
Sand and silt
Permanent flow

Group 11 Poa labillardieri - Myriophyllum
Sand and silt
Permanent flow

Group 12 Pteridium esculentum
Sand and silt
< 1 in 6 month flow

Group 13 Juncus kraussii - Plantago
Sand and silt
1 in 6 month to 1 in 12 month flow

Group 14 Ruppia megacarpa
Sand and silt
Permanent flow

4.5 Discussion

Cowles (1901) described vegetation variation on flood plains near Chicago, U.S., in relation to stream grade. This perceptive paper associated vegetation patterns with physiographic forms and processes. He noted a trend in riparian vegetation from xerophytic (upland) to mesophytic (bottomland), and this trend coincided with stream development from ravines (steep grade) to mature streams (gentle grade). The destructive action of currents and depositional processes were cited as probable causes of variation in the vegetation patterns. Since this study, little further research has been undertaken examining relations between physiography and riverine communities, and this is especially so in Australia.

This chapter has examined the distribution of riverine plant communities along the Swan and Apsley Rivers in eastern Tasmania with respect to longitudinal and cross-sectional position. Fourteen communities were identified ranging from aquatic hydrophytic communities growing in the main river channel to woody communities growing in periodically inundated areas. The communities are distributed along the length of each river and may generally be divided into upland and lowland communities, though a considerable amount of overlap exists in the middle reaches. Deviations from a general longitudinal pattern are due to local variations in geology, geomorphology or gradient. Cross sectional distributions of the communities are discrete and are closely associated with flow frequency and substrate.

Longitudinal variability of plant communities due to water chemistry was demonstrated by ordinating the data. Communities at the mouth of the Swan River, which are influenced by brackish to saline waters are distinctively grouped. Within the freshwater component of both rivers, other environmental influences dominate.

Longitudinal variation along the Swan River is most closely associated with geological change. Community variation along the Apsley River, by contrast, is explained by both geology and gradient index. The stream profile for the Apsley River is typically that of an actively adjusting and down-cutting river (fig 92). Where the Apsley emerges from the Apsley Gorge (below the 'hump' on the profile), the river is continually changing course and undercutting the banks. Former stream channels are evident (see profiles) and the stream environment is a mobile and dynamic one. It is of interest to note that erosion and undercutting of the banks (and riparian vegetation) along the Apsley River at Rosedale are most certainly due to the continual adjustment of the river, and not solely due to forestry practices in the upper part of the Apsley River catchment (The Wilderness Society et al. 1985).

Longitudinal variation of the aquatic community (group 10) is due to patchiness of environments in which to colonize. Exclusion of aquatic communities from the headwaters reflects an intolerance of aquatic species to shade (created by woody riparian vegetation along small upland channel courses). In the mid reaches and lower reaches of the rivers riparian clearance has been conducive to colonization of aquatic plants, due to diminution of shade and increases in deposited sediment (through bank erosion). Occurrence of aquatic communities in the upper catchment is coincident with local deposition of fine substrate or the clearance of bank vegetation e.g. the building of unsealed roads by the Tasmanian Forestry Commission removes shade and increases the supply of sediment to streams.

In their study of the riparian and aquatic vegetation of the River Wye, Merry et al. (1981) concluded that geology played an important role in the variation of communities downstream, and that tolerance of submergence, alluvial deposition and erosion, and competition played a major role in determining each species position on the bank. Curry and Slater (1986) suggested that the most important influences

governing river corridor vegetation along four catchments in Wales was altitude, gradient, underlying geology and intensity of shade.

Cross-sectional variability of plant communities for the Swan and Apsley Rivers is due to flow frequency and substrate. Variations due to flow frequency are higher for the Apsley River than the Swan River. The Apsley River experiences high specific peak flows (1.504 $m^3/s/km^2$), which may account for this difference (the Swan River has equivalent flows of 1.179 $m^3/s/km^2$). However, it is true to say that substrate mobility and deposition is closely associated with flow frequency which accounts for the significant F values for both rivers.

These findings are further emphasized by an examination of community structure. Species richness and diversity is greatest in the middle reaches of both rivers, possibly due to the maximization of environmental heterogeneity and the mixing of high catchment and low catchment communities. There is no significant variation in species richness and diversity across the transects, demonstrating evenness in structure between plant communities along the same transect. The longitudinal change in structure and community types for each river is clarified by beta turnover rates, which are high and range from 0.2 to 1.0 (figures 91 and 92). Bell and del Moral (1977) found that species richness and species diversity tended to increase with increasing maturity and decreasing flood stress. Mature, unflooded uplands supported the greatest number of species and the greatest species diversity.

Sigafoos (1964) demonstrated that overbank flow may damage trees or inhibit germination, but vegetational and sedimentological evidence of floodplain inundation did not relate consistently to a specific flow frequency. However, the analysis of Gregory (1976) of the truncated distribution of lichen thalli on bedrock channel walls provides an unambiguous correlation of a vegetational limit to a

particular flow, the discharge at the lichen limit having a return period of 1.14 to 1.37 years. Hupp (1982) also suggested that riparian forest along Passage Creek, Virginia, may result from periodic disturbance by destructive floods.

Fluvial processes such as erosion and deposition have been shown to be important in determining the zonation of species on river banks (Lindsey et al. 1961, Johnson et al. 1976) and producing heterogeneity of habitats. This is emphasized by Nilsson (1986) who concludes that substrate and current velocity are the main factors in causing deviations from a longitudinal gradient of riparian vegetation.

The evidence of flow frequency and substrate being major influences on the cross-sectional distribution of riverine vegetation for the Swan and Aspley Rivers is pertinent, especially in the light of recent attention received by the rivers in this area (Kirkpatrick 1986, The Wilderness Society et al. 1985, Duncan 1983) and the possible effects of forestry activities on their hydrology. Table 15 indicates the range of environments (as sampled in this survey) experienced by the 10 rare and endangered species listed in section 4.4.1. Given the discrete cross-sectional communities in which these species grow and their association with particular substrates and flow frequencies, alteration of the hydrology through clearfelling may greatly alter the riverine vegetation, a problem that has been discussed by Franz and Bazzaz (1977) and Teskey and Hinckley (1979).

There are no Australian data with which to compare these results. Thus valid comparisons between mainland riverine plant communities and those along the Swan and Apsley Rivers are not possible. Eucalyptus dominated riverine communities are absent along the study rivers, but are important along inland water courses of mainland Australia (Beadle 1981) e.g. Eucalyptus camaldulensis (River Red Gum). Eucalyptus ovata, sampled in this survey, favours swampy environments

Species	River Catchment	Frequency of plot occurrence	Plant community (as defined in section 4.4.2)	Substrate	Flow frequency	Geology
Pultanaea selaginoides	Apsley	2	4	sand and silt	1 in 12 month to 1 in 22 month flow 82.6 to 109.2 cumecs	sandstone, siltstone and alluvial sands
Spyridium microphyllum	Swan	7	5 and 3	boulders, unconsolidated cobble and pebble	1 in 12 month to 1 in 10 year flow 165 to 609 cumecs	dolerite and sandstone
Callitris oblonga	Apsley Swan	18	4 and 3	solid rock to sand and silt	<1 in 6 month to 1 in 10 year flow <51.2 to 609 cumecs	dolerite and alluvial sands
Dodonaea ericifolia	Apsley Swan	2	3 and 4	boulders, sand and silt	1 in 6 month to 1 in 22 month flow 74 to 238 cumecs	dolerite and sandstone
Phebalium squameum spp. retusum	Apsley	2	3	boulders	1 in 6 month to 1 in 12 month flow 51.2 to 82.6 cumecs	sandstone, mudstone and carbonaceous sequences
Odixia angusta	Apsley	6	4	sand and silt	<1 in 6 month to 1 in 22 month flow <51.2 to 109.2 cumecs	sandstone, siltsone and alluvial sands
Lasiopetalum micranthum	Swan	5	3,4 and 5	consolidated and unconsolidated cobble	<1 in 6 month to 1 in 10 year flow <74 to 609 cumecs	dolerite
Spyridium obovatum var. velutinum	Swan	1	5	consolidated cobble and pebble	1 in 22 month to 1 in 10 year flow 238 to 609 cumecs	dolerite
Melaleuca pustulata	Swan	49	2,3,4,5,7,9,10	all substrates	all discharges (except permanent water)	dolerite, sandstone, alluvial sands and gravel
Spyridium obovatum var. obovatum	Apsley Swan	41	3,4, and 5	all substrates	>1 in 6 month flow >51.2 cumecs	dolerite (predominantly), alluvial sands and gravel, sandstone, mudstone

Table 15. Range of environments of 10 rare and endangered species along the Swan and Apsley Rivers

but is not an obligate riverine species. Casuarina cunninghamiana occupies riverine habitats in the east of Australia from southern New South Wales to the Cape York Peninsula, but in general few species are rigidly confined or associated with flowing water. Similarly, in Tasmania there appears to be a strong representation of woody species along water courses. Although there is an absence of many obligate riverine species along the Swan and Apsley Rivers (as is the case elsewhere in Australia), the actual assemblage of species is very much confined to a riverine environment. Thus facultative riverine species are unlikely to be found growing in the same community in other environments.

This study concludes that well-defined groupings of plant communities along the Swan and Apsley Rivers do not exist. The longitudinal continuity of communities as envisaged by Vannote et al. (1980) and Minshall et al. (1983) is neither applicable nor appropriate, and instead a scheme linking physiographic processes and vegetational patterns is proposed. Species diversity and richness is highest in the midreaches of both rivers which may reflect maximization of environmental heterogeneity. Longitudinal variation in plant communities is attributed to changes in geology and gradient index. Superimposed upon these patterns are cross-sectional ones, where community changes away from the channel are attributed to substrate and flow frequency. The terrestrial setting of the stream greatly influences distributions of aquatic plant communities along both rivers in terms of suitable substrate for colonization and the effects of shading by riparian species.

Chapter 5

Distribution of plant communities along rivers in Tasmania

5.1 Introduction

River plants can be sensitive indicators of environmental conditions (Haslam 1978). In Tasmania, where there is a range of hydrological and chemical lotic environments (chapter 2), it may be possible to associate specific aquatic plant communities with particular habitats. Similar studies have been undertaken for the rivers of Central Europe (Wiegleb 1981a), and for the rivers of Britain (Haslam 1978, Goriup 1978, 1979, 1981).

This chapter examines distributions of aquatic macrophytes at the regional scale, with the aim of elucidating which environmental parameters are the most important in influencing the presence and absence of species along rivers in Tasmania.

5.2 Methods

The presence/absence of aquatic macrophytes (here defined as obligate aquatic plants) were sampled along 311 50 metre lengths of 31 selected rivers in Tasmania (fig 93). The 50 metre lengths of river were located from the 1:100.000 topographic series for Tasmania, and were chosen with the aim of sampling as diverse a range of lotic environments as possible. Rivers were sampled from the four hydrological groups identified in chapter 2, and from a variety of chemical environments (in terms of filterable residue and colour, see chapter 2). Individual water samples were obtained from each sample site, and were tested for filterable residue and colour. The individual sites were assigned to a hydrological category based on the regionalization in chapter 2. Additionally, subjective notes were made on substrate type (sand and silt, cobble and

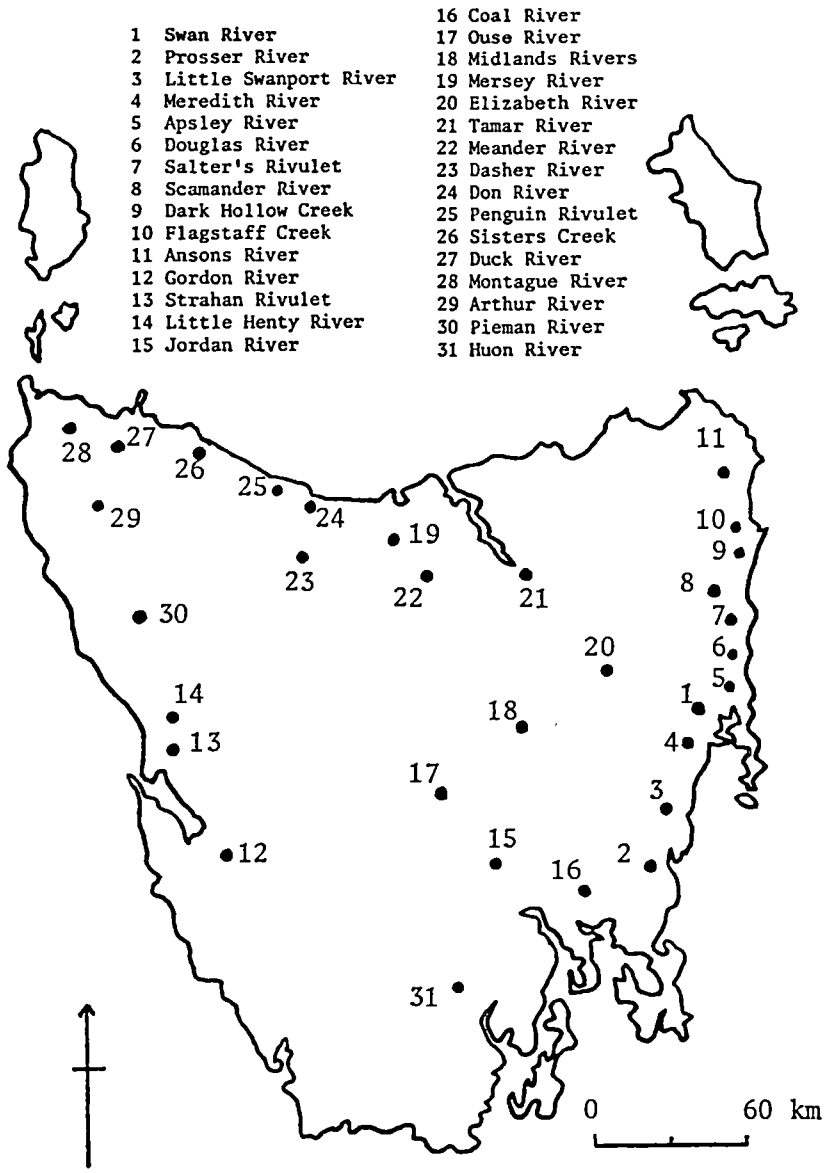


Fig. 93. General location of the rivers sampled in the geographical survey of riverine aquatic plants

pebble, boulders and solid rock), and on the degrees of shading from riparian vegetation (completely shaded no shade, some shade).

The presence/absence data from the 278 samples containing aquatic vegetation (33 with no vegetation) were initially analysed using ordination and classifiction procedures (detrended correspondence analysis and two way indicator species analysis respectively, Hill 1979a, 1979b). This enabled patterns of similarity between samples to be distinguished, and provided a working classification of lotic plant communities for Tasmania.

Multiple discriminant analysis (SPSSX 1986) was used in order to examine which environmental parameters might be of importance in controlling patterns of plant distributions. This method has been used effectively in lotic environments by Wiegleb (1981a) and Bunn et al. (1986), and has been highly recommended as an analytical tool for aquatic ecologists by Green and Vascotto (1978). Multiple discriminant analysis was applied to the environmental variables using the seven groups derived from TWINSPAN (and an eighth group for 33 x 50 metre stretches of river with no vegetation) in a manner similar to that recommended by Green and Vascotto (1978).

Nomenclature, unless otherwise stated, follows that of Aston (1973), Orchard (1985), Curtis (1963, 1967), Curtis and Morris (1975), Willis (1970) and Sainty and Jacobs (1981).

5.3 Results and discussion

Sixty-six species of obligate aquatic (or marginal) plants were sampled in this study. This represents approximately 70% of the obligate aquatic flora of Tasmania (Aston 1973) and includes two endemic aquatic species (Nymphoides exigua and Lilaeopsis brownii) as well as Utricularia australis which is rare to the State (Curtis 1967). The species found in this survey are listed in appendix 7.

The ordination and classification of the 278 samples is displayed in figure 94, and table 16 lists the percentage frequency of aquatic species sampled in each community. Seven groups are identified, but only the three major groups are plotted on the ordination axes. Indicator and frequently occurring species are plotted in the species ordination below. There is a distinction along axis 1 (eigenvalue=0.729) between the seagrasses and brackish water species (*), and those occurring in freshwater environments. Axis 2 distinguishes between marginal herbfield aquatic communities (groups 1 and 2 ●) and groups dominated by Triglochin procera and other hydrophytes (+).

The indicator (and frequently occurring) species for each community are as follows:

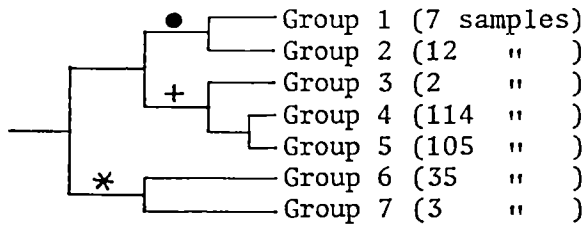
Group 1 Potamogeton ochreatus
(Callitriche stagnalis)

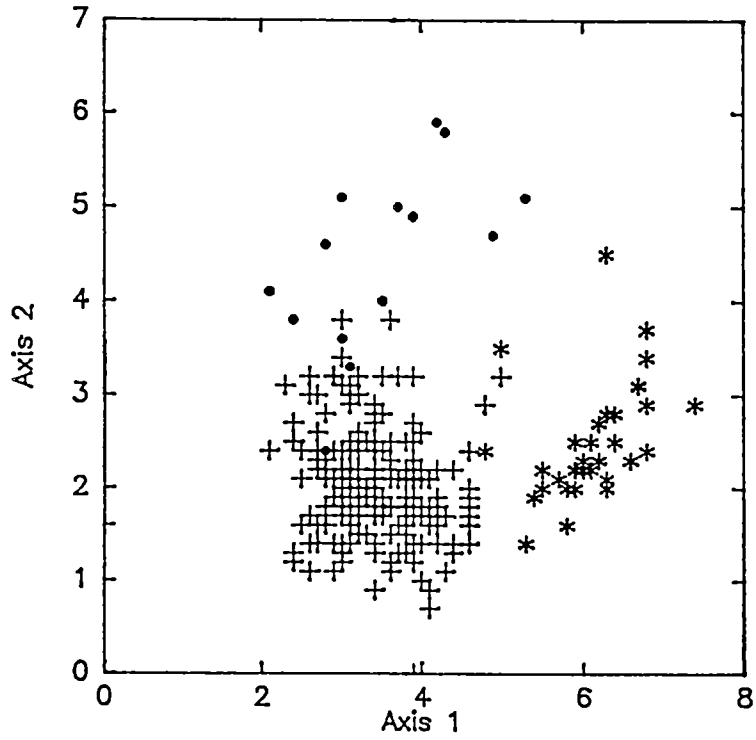
Group 2 Typha orientalis
(Callitriche stagnalis)

Group 3 Nasturtium microphylla
(Lilaeopsis brownii)
(Typha orientalis)
(Triglochin procera)

Group 4 Myriophyllum simulans
Eleocharis acuta
Villarsia reniformis
Scirpus fluitans
Ranunculus rivularis
(Triglochin procera)

Group 5 Phragmites australis
Schoenus fluitans
(Triglochin procera)
(Eleocharis sphacelata)





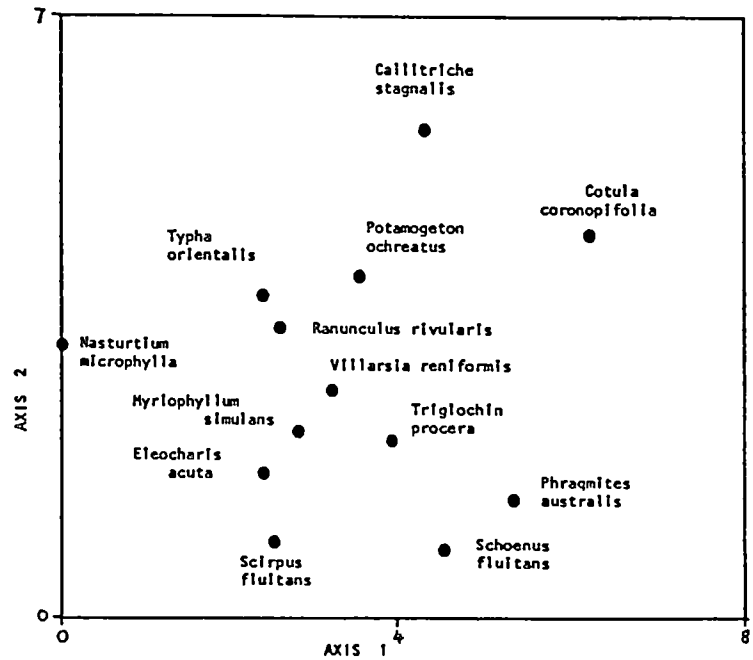


Fig. 94. Ordination and classification of riverine aquatic plants in Tasmania. The species ordination is plotted below

Group 1

SPECIES	FREQ	(PCNT)
51 junc arti	1	14.29
5 eleo spha	1	14.29
12 cotu coro	1	14.29
18 call stag	3	42.86
26 pota ochr	6	85.71

Group 2

SPECIES	FREQ	(PCNT)
8 trig proc	1	8.33
9 lila brow	1	8.33
2 vill reni	1	8.33
32 clay aust	1	8.33
61 azol fili	1	8.33
26 pota ochr	1	8.33
33 lemn mino	2	16.67
13 ranu rivu	2	16.67
36 lepi sp	2	16.67
29 nast offi	4	33.33
51 junc arti	5	41.67
21 typh orie	5	41.67
18 call stag	8	66.67

Group 3

SPECIES	FREQ	(PCNT)
8 trig proc	1	50.00
21 typh orie	1	50.00
9 lila brow	1	50.00
44 nast micr	2	100.00

Group 4

SPECIES	FREQ	(PCNT)
66 wate lily	1	0.88
65 spir odel	1	0.88
55 myri vari	1	0.88
12 cotu coro	1	0.88
63 utri dich	1	0.88
31 rupp poly	1	0.88
53 typh domi	1	0.88
59 lemn tris	1	0.88
33 lemn mino	1	0.88
11 myri amph	1	0.88
28 halo sp	1	0.88
50 myri vari	1	0.88
34 utri aust	1	0.88
61 azol fili	1	0.88
56 calt phyl	1	0.88
64 alis plan	2	1.75
57 gunn cord	2	1.75
27 pota pect	2	1.75
3 vill exal	2	1.75
60 vall giga	2	1.75
47 hydr musc	2	1.75
58 ranu trip	2	1.75
30 rupp mega	2	1.75
35 nymp exig	2	1.75
45 cras helm	3	2.63
42 Ranu inun	3	2.63
39 isot fluv	3	2.63
18 call stag	3	2.63
7 trig stri	4	3.51
62 junc pall	4	3.51
15 myri sals	4	3.51
54 poly hydr	4	3.51
51 junc arti	4	3.51
49 hydr pter	5	4.39
17 rume bide	5	4.39
40 elod cana	7	6.14
19 scho flui	7	6.14
1 cent cord	7	6.14
29 nast offi	8	7.02
37 ranu tric	8	7.02
16 phra aust	9	7.89
4 hydr java	9	7.89
43 elat grat	10	8.77
41 cent mini	10	8.77
36 lepi sp	10	8.77
32 clay aust	13	11.40
14 nite lla	13	11.40
46 pota aust	13	11.40
9 lila brow	13	11.40
23 pota perf	14	12.28
26 pota ochr	15	13.16
22 grat nana	15	13.16
21 typh orie	19	16.67
24 pota trie	20	17.54
25 char sp	22	19.30
20 myri pedu	23	20.18
13 ranu rivu	24	21.05
38 scir flui	24	21.05
2 vill reni	36	31.58
5 eleo spha	37	32.46
6 eleo acut	45	39.47
52 myri simu	77	67.54
8 trig proc	87	76.32

Table 16. Percentage frequency of aquatic species sampled in each community

Group 5

	SPECIES	FREQ	(PCNT)
38	scir flui	1	0.95
23	pota perf	1	0.95
18	call stag	1	0.95
2	vill reni	1	0.95
39	isot fluv	1	0.95
29	nast offi	1	0.95
11	myri amph	2	1.90
4	hydr java	2	1.90
24	pota tric	2	1.90
60	vall giga	2	1.90
54	poly hydr	2	1.90
45	cras helm	3	2.86
17	rume bid	3	2.86
6	eleo acut	3	2.86
13	ranu rivu	3	2.86
40	elod cana	4	3.81
14	nite lla	4	3.81
41	cent mini	6	5.71
51	junc arti	6	5.71
21	typh orie	7	6.67
20	myri pedu	8	7.62
46	pota aust	8	7.62
26	pota ochr	10	9.52
25	char sp.	10	9.52
22	grat nana	10	9.52
9	lila brow	11	10.48
43	elat grat	11	10.48
52	myri simu	14	13.33
15	myri sals	19	18.10
19	scho flui	26	24.76
5	eleo spha	26	24.76
16	phra aust	51	48.57
8	trig proc	87	82.86

Group 6

	SPECIES	FREQ	(PCNT)
20	myri pedu	1	2.86
33	lemn mino	1	2.86
2	vill reni	1	2.86
26	pota ochr	1	2.86
34	utri aust	1	2.86
5	eleo spha	2	5.71
19	scho flui	2	5.71
12	cotu coro	3	8.57
8	trig proc	5	14.29
15	myri sals	8	22.86
36	lepi sp.	9	25.71
27	pota pect	9	25.71
48	apiu aust	10	28.57
28	halo sp.	17	48.57
31	rupp poly	19	54.29
10	zost muel	20	57.14
30	rupp mega	22	62.86
16	phra aust	28	80.00

Group 7

	SPECIES	FREQ	(PCNT)
31	rupp poly	1	3.33
10	zost muel	2	6.67
12	cotu coro	3	100.00

Table 16 (continued)

Group 6 *Phragmites australis*
(*Ruppia megacarpa*)
(*Zostera muelleri*)

Group 7 *Cotula coronopifolia*
(*Zostera muelleri*)

Within river catchments, the only well defined groups are the seagrasses and other brackish environment species. The other communities tend to occur non-uniformly along rivers, with the exception of alpine aquatic communities which are located in the upper reaches of the Ouse River (*Myriophyllum simulans* with *Lilaeopsis brownii*, *Ranunculus triplodontus* and *Caltha phylloptera*). The species in the upper catchment communities are not exclusive to these environments and are thus not in a separate group.

The results of the discriminant analysis (table 17) reveal that the first discriminant function accounts for 50.58% of the variation, with high absolute DF coefficients for filterable residue (total dissolved solids) and colour (which correlates with pH, see chapter 2). Discriminant function II accounts for 36.13% of the variation, with substrate as well as filterable residue having the highest absolute DF coefficients. Discriminant function III only accounted for 8.17% of the variance (and is therefore not listed in the table), but has a high absolute DF coefficient for hydrology. The degree of shading by riparian vegetation appears to have no influence on plant distributions at this scale. The group centroids for each of the three discriminant functions are as follows:

Variable	Discriminant function 1	11
Filterable residue	-0.83	1.33
Colour	0.63	0.43
Hydrology	-0.24	0.06
Shade	0.47	0.16
Substrate	0.24	-1.41
% variance explained	50.58	36.13

Table 17. Canonical discriminant function coefficient of physical and chemical variables for the groups of the TWINSPAN classification

Group	DF 1	DF 11	DF 111
1	0.69	-0.01	1.00
2	-0.02	0.88	-0.18
3	-0.29	1.36	-1.03
4	0.45	0.41	0.19
5	-1.67	0.99	-0.09
6	2.00	-0.77	-0.64
7	2.09	-0.79	-0.35
8	-1.41	-1.85	-0.06

These demonstrate that groups 6 and 7 (and to a lesser extent group 5 and 8) are the most influenced by filterable residue and colour. Group 8 (devoid of vegetation) followed by group 3 is most highly influenced by substrate, and hydrology influences communities in groups 1 and 3.

Figure 95 displays groups derived from the TWINSPAN classification on the first two discriminant functions. The bottom left portion of the diagram represents those lotic communities that are unsuitable for aquatic plant growth i.e. low values of filterable residue (<50 p.p.m.), high colour values (>100 hazen units) and/or pebble to boulder substrate. The bottom (to top) right portion of the diagram has highly brackish to saline environments (>150 p.p.m.) and a variety of substrates (groups 6 and 7). The top left hand side of figure 95 represents environments with fine substrate, low salinites and high colour values (group 5 communities). The top centre of the diagram (which contains the greatest diversity of communities) contains environments that have filterable residue values ranging from 50 to 150 p.p.m. and fine to pebbly substrates (groups 2,3,4) i.e. the optimum environments for freshwater aquatic plant communities in Tasmania.

The geographic patterning of communities shows that west coast rivers e.g. Gordon River, tend to support group 5 communities with low species richness. Triglochon procera, Myriophyllum amphibium and Potamogeton ochreatus were the

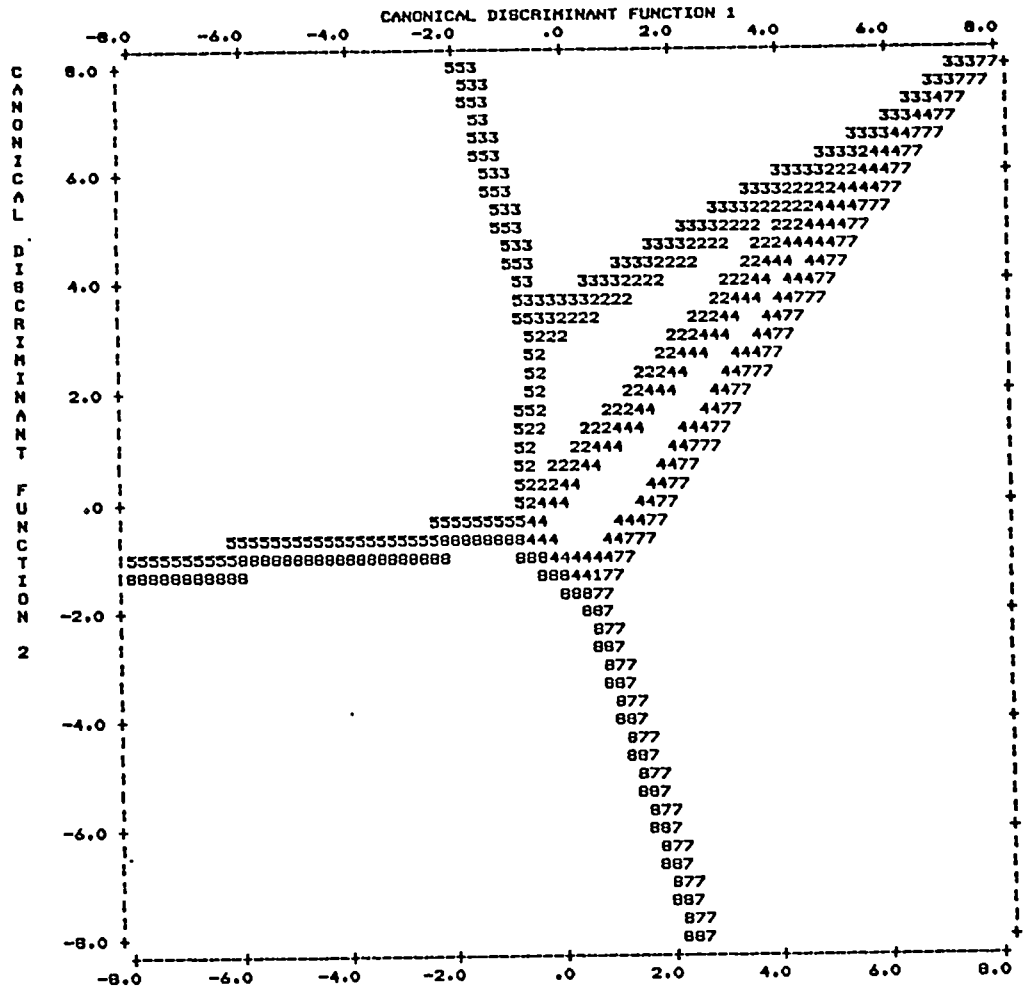


Fig. 95. The separation of groups derived from TWINSPAN on the first two discriminant functions of the environmental variables. The lines of group members represent the margin of the distribution of the group

only species found in these samples. By contrast rivers in the east coast region have species rich communities along their midreaches (18 species were found in two samples along the midreaches of the Little Swanport River), and the introduced aquatic plant Elodea canadensis favours this region. No group 6 or 7 communities were found on the west coast, which probably reflects the dynamic environment of estuaries in this region and unsuitable substrate. Species rich communities (groups 2, 4 and 5) were found in the north and north west of the State, where there are suitable substrate and chemical environments.

No Australian data were found with which to compare these results. However, the varying importance of water chemistry and substrate in the distribution of aquatic plants along rivers in Tasmania does reinforce the findings of Haslam (1978) who identified assemblages of aquatic plants specific to geological, chemical and flow environments in Britain. Similarly Wiegleb (1981a) concluded that plant distributions along rivers in Central Europe were much influenced by the water chemistry, though in this region this also reflected high levels of pollution in some rivers.

It is surprising that the presence/absence of species along rivers in Tasmania is not (apparently) influenced by the hydrology (to any great extent). This may, however, reflect the scale of this study, and the overwhelming importance of chemistry and substrate e.g. the brackish communities at the mouth of the Swan River and the oligotrophic communities in the upper reaches are both categorised under hydrological group 2 (chapter 2). Conversely, the lack of influence of hydrological variation on presence/absence of species may reflect a flora that is highly adapted to a variable environment.

Kirkpatrick and Harwood (1983a), in their survey of Tasmanian enclosed wetlands, found that salinity and permanence of water accounted for over one-third of the variance between the 16 wetland communities, while pH had

more influence than permanence in the freshwater wetlands alone. Colour and pH are significantly correlated for Tasmanian rivers (chapter 2) indicating that pH as well as colour may account for variance between riverine aquatic plant communities.

Thus the presence/absence of obligate aquatic macrophytes along 31 Tasmanian rivers is dictated by water chemistry and substrate, and these are the most important influences determining the distributions of seven aquatic plant communities.

Chapter 6

Conclusions

6.1 Summary of findings

*Is it more appropriate to consider a characteristic level of disturbance rather than 'homogenous' geographical subdivisions as a framework within which to examine lotic plant communities?

The study has demonstrated the variability of hydrological and chemical environments in Tasmania, and the appropriateness of a hydrological regionalization for the State. This has provided a suitable framework of investigation for examining distributions of riverine plants. It is recommended that future stream ecological work (whether botanical or zoological) attempt to quantify stream environments in terms of annual, monthly, low and peak flows and water chemistry, in order to gain some idea of the variability of lotic habitats. Thus more meaningful comparisons within- and between-catchments are possible, and a better understanding of disturbance processes may be gained.

* Can lotic plant communities be regarded as individualistic plant assemblages, that are the result of recurrent disturbances?

Non equilibrial or stochastic processes were found to be important in regulating assemblages of aquatic plants along the Swan and Apsley Rivers in eastern Tasmania. Discharge fluctuations occurred sufficiently frequently to maintain an individualistic community, where the species were assembled through converging accidents of space, time and similar environmental needs.

* Do lotic communities owe their diversity and species richness to the frequency and magnitude of disturbances?

At the plot scale, the structure of aquatic plant communities along the Swan and Apsley Rivers was found to be directly related to hydrological variation. There is a tendency towards species polydominance which supports an individualistic, abiotic interpretation of community structure and change. Communities in the midreaches of the streams displayed the greatest resistance to structural change.

* Do environmentally adapted lotic species reestablish after a disturbance by means of successional mechanisms?

Disturbance environments tend to favour opportunistic species that recover rapidly vegetatively i.e.low resilience at the community scale but high resilience at the species scale. The evidence of site-specific succession in this study does not support an organismic interpretation, and changes in community structure tended to be random.

* Can changes in species composition or cover in lotic plant communities be predicted from life history characteristics of individual plant species?

All the species sampled in this survey exhibit some morphological adaptation suitable to a disturbance environment in streams (i.e. r-selected species). If tubers or rootstocks remain whilst vegetative parts are removed during a flood or low flow period, then there is a high chance of that species resprouting under favourable conditions. Colonization by new propagules is a random phenomena, but dependent on the availability of seed or vegetative fragments from upstream or elsewhere. The dependent factors for predicting changes in the communities are timing of the disturbance as well as life history characteristics.

* Is the diversity and richness of riverine plants highest in the midreaches of streams where there is (possibly) maximization of environmental variability?

Species richness and diversity is highest in the midreaches of the Swan and Apsley Rivers. The midreach riverine communities represent a mixture of upper catchment and lower catchment species. Additionally, environmental heterogeneity is maximized in the middle reaches of both streams, where the range of hydrological and substrate environments is greatest.

* Are plant communities distributed in a continually varying fashion downstream in response to a 'continuous' or 'intergrading' longitudinal gradient of environments?

Longitudinal continuity of communities as envisaged by Vannote et al. (1980) is not applicable to the Swan and Apsley Rivers. Instead, a scheme linking physiographic processes and vegetational patterns is proposed. Riverine plant communities are thus a direct reflection of a variable environment, which is not necessarily a longitudinal one.

* Is the distribution and species composition of aquatic vascular plant communities influenced by the nature of the riparian communities and the terrestrial setting of the stream?

It is apparent along the Swan and Apsley Rivers that aquatic macrophytes are absent from heavily shaded parts of the stream channel, but tend to colonize stretches where riparian vegetation does not grow or has been cleared e.g. through forestry and agricultural activities.

* Are deterministic physico-chemical processes a major influence on the distribution of plant communities along the length of a river?

The study demonstrated the importance of geology and gradient index in the longitudinal distribution of riverine plant communities. Superimposed upon this deterministic pattern is a cross-sectional one, where community changes away from the channel are attributed to substrate and flow frequency.

* Is the presence/absence of plant species between river catchments determined by dynamic physico-chemical processes?

A geographical survey of presence/absence of obligate aquatic macrophytes along 31 Tasmanian rivers revealed that chemistry and substrate were the most important influences determining distributions at this scale. It is apparent that hydrological variability better explains community structure at the plot and catchment scale, rather than presence/absence of species at the regional scale.

6.2 Management of riverine plants

The study concludes that predictable spatial patterns are found in riverine communities in Tasmania at the regional and catchment scales. Large scale prediction, at say the plot or stream-reach scale, is more problematic. Unpredictable hydrological variability accounted for changes in community structure at the plot scale, while water chemistry and substrate characteristics determined between-catchment species composition. There were no predictable patterns over time at the plot scale, though a study spanning a time period of 15 years or more may reveal longer-term trends.

The results also demonstrate that managing riverine plant communities is an activity that can only occur appropriately at the catchment scale. Reservation of small stretches of river (stream-side reserves) is unsuitable for conserving rare aquatic species, due to the changing and mobile nature of the communities. The situation is different for riparian species which assumed a more deterministic distribution. Nevertheless, the maintainance of riparian communities is an integral part of riverine management, as a means of conrolling aquatic communities (through shading) and to prevent bank erosion and substrate deposition.

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APPENDIX 1

List of the 13 hydrological variables used for each of the 77 gauging stations in the hydrological regionalization

	Catchment area (km^2)	Cv annual flows	Cs annual flows	r_1 annual flows
Andersons Creek	49.5	0.4483	0.2420	0.3724
Apsley River	155	0.7879	1.561	0.0424
Arm River	86	0.2567	0.684	-0.1197
Arthur River	1535	0.2816	0.405	-0.0449
Birralee Creek	33	0.958	1.327	0.0197
Black River	324	0.322	0.639	0.2517
Brid River	139	0.4662	1.036	0.1455
Browns River	11.1	0.4990	0.887	0.3402
Cam River	221	0.4324	0.661	0.2835
Carlton River	141	0.757	0.55	0.3154
Claytons Rivulet (Sprent)	13	0.5337	0.673	0.2498
Claytons Rivulet (Bass Highway	47.9	0.432	0.460	0.2202
Clyde River (Hamilton)	1012	0.9135	1.105	0.2669
Clyde River (Crescent)	208	0.7658	1.0773	0.2019
Coal River (Baden)	53.2	0.8527	0.873	0.5133
Coal River (Craigbourne)	247	0.8803	1.0606	0.1629
Coal River (Kangaroo)	303	0.8884	1.022	0.3082
Davey River	686	0.1646	0.0181	-0.1961
Derwent River	7060	0.2087	1.0936	-0.2082
Don River	128	0.587	0.615	0.3672
Duck River	339	0.3531	-0.807	-0.4244
Dulverton Rivulet	138	1.0846	1.805	0.2679
Emu River	92.7	0.507	0.430	0.5605
Esperance River	175	0.1479	-0.9451	-0.6382
Flowerdale River	152	0.2907	-0.0383	0.12991
Forth River	311	0.2563	0.3897	-0.2694
Franklin River (Jane)	1590	0.2255	0.4455	-0.3714
Franklin River (Mt. Finsham)	757	0.2176	0.593	-0.3252
Florentine River	436	0.2480	0.453	-0.2569

	M.A.R. (mm)	Cv monthly flows	Cv monthly peaks	Cv monthly lows
Andersons Creek	423	0.9040	0.8110	1.5752
Apsley River	402	0.4032	0.7455	1.3911
Arm River	1082	0.6527	0.6242	0.6393
Arthur River	1179	0.6621	0.4966	0.7688
Birralee Creek	64	0.9715	0.9932	1.4545
Black River	738	0.6942	0.5692	1.3482
Brid River	390	0.5875	0.5033	0.7390
Browns River	399	0.4262	0.3955	0.9105
Cam River	684	0.8740	0.8753	1.0528
Carlton River	143	0.5564	0.5806	1.4185
Claytons Rivulet (Sprent)	564	0.8165	0.7164	1.3691
Claytons Rivulet (Bass Highway)	532	0.7003	0.6918	1.2844
Clyde River (Hamilton)	79	0.6094	0.6279	0.4686
Clyde River (Crescent)	169	0.3902	0.5344	1.0504
Coal River (Baden)	143	0.9310	0.4204	2.0579
Coal River Craigbourne)	71	0.7140	0.5737	1.4413
Coal River (Kangaroo)	75	0.6978	0.6456	1.7329
Davey River	1933	0.3916	0.3495	0.5648
Derwent River	486	0.3524	0.4776	0.4054
Don River	562	0.8972	0.7834	1.4599
Duck River	588	0.7669	0.6194	1.0232
Dulverton Rivulet	29	0.8784	0.9738	1.9935
Emu River	1172	0.6377	0.5038	0.8014
Esperance River	705	0.5189	0.5068	0.7095
Flowerdale River	806	0.6342	0.5209	0.8343
Forth River	1480	0.5512	0.4623	0.8159
Franklin River (Jane)	1872	0.4121	0.3800	0.5329
Franklin River (Mt. Finsham)	1973	0.4654	0.3071	0.4182
Florentine River	883	0.4399	0.5211	0.3191

	Specific peaks $\bar{Q}$ ($m^3/s/km^2$)	Iv log peak flows	g log peak flows
Andersons Creek	0.4813	0.3154	-0.5648
Apsley River	1.504	0.2818	0.3279
Arm River	0.3846	0.1464	1.3397
Arthur River	0.4576	0.1353	0.2391
Birralee Creek	0.2208	0.5859	-0.1702
Black River	0.3953	0.1360	1.7221
Brid River	0.1826	0.2813	-0.3688
Browns River	0.9174	0.5250	-0.1093
Cam River	0.6765	0.2856	-0.5201
Carlton River	0.7161	0.6462	-0.9203
Claytons Rivulet (Sprent)	0.2855	0.2370	-0.2722
Claytons Rivulet (Bass Highway)	0.1899	0.2169	-0.5501
Clyde River (Hamilton)	0.1085	0.6296	-0.4461
Clyde River (Crescent)	0.0136	0.6449	-2.2870
Coal River (Baden)	0.2268	0.5444	-0.3730
Coal River Craigbourne)	0.2569	0.7535	-0.6136
Coal River (Kangaroo)	0.1841	0.8162	-1.0427
Davey River	0.5792	0.0900	0.0275
Derwent River	0.1043	0.2773	0.5419
Don River	0.3440	0.3007	-1.1146
Duck River	0.1917	0.1050	0.0588
Dulverton Rivulet	0.1068	1.0083	-0.9833
Emu River	0.4317	0.1639	-0.0337
Esperance River	0.5863	0.2615	0.3724
Flowerdale River	0.4364	0.1917	-1.0749
Forth River	0.6445	0.1441	1.5815
Franklin River (Jane)	0.7021	0.1220	0.4716
Franklin River (Mt. Finsham)	0.8797	0.1250	0.4114
Florentine River	0.1877	0.1917	0.4548

	Iv low flows	Specific lows $\bar{Q}$ $(m^3/s/km^2)x10^{-4}$
Andersons Creek	1.2615	1.3131
Apsley River	2.4112	0.6903
Arm River	0.3707	19.3837
Arthur River	0.2216	36.9381
Birralee Creek	0.0000	0.0
Black River	0.4725	9.327
Brid River	0.4586	24.25
Browns River	0.8	8.558
Cam River	0.5674	24.5928
Carlton River	2.2759	0.2057
Claytons Rivulet (Sprent)	1.1538	5.0
Claytons Rivulet (Bass Highway)	1.5933	9.3946
Clyde River (Hamilton)	1.4864	1.3083
Clyde River (Crescent)	0.9896	2.3173
Coal River (Baden)	0.0000	0.0
Coal River Craigbourne)	2.5135	0.004
Coal River (Kangaroo)	2.3692	0.2145
Davey River	0.3736	28.3542
Derwent River	0.3866	3.9603
Don River	0.7208	7.2188
Duck River	0.4769	20.3068
Dulverton Rivulet	5.0000	0.0145
Emu River	0.4950	38.5329
Esperance River	0.2117	15.0629
Flowerdale River	0.3373	34.9737
Forth River	0.5671	16.4309
Franklin River (Jane)	0.2134	53.3151
Franklin River (Mt. Finsham)	0.2382	46.6764
Florentine River	0.2239	43.1239

	Catchment area (km^2)	Cv annual flows	Cs annual flows	r_1 annual flows
Gawler River	85.9	0.4507	0.2632	0.0012
George River	405	0.5426	0.8883	0.2436
Gordon River	458	0.2172	0.3946	-0.3431
Great Musselroe River	352	0.4615	0.5530	0.3515
Hellyer River	102	0.2606	0.425	-0.2356
Henty River	116	0.1496	0.2235	-0.2952
Huon River	1829	0.2175	0.357	-0.0861
Inglis River	172	0.2687	-0.2341	-0.1241
Iron Creek	94.8	0.8045	0.588	-0.0164
Jordan River	742	0.9102	0.7082	-0.0279
King River	449	0.1801	-0.18	-0.0935
Lake River	421	0.5069	1.36	-0.0219
Leven River	500	0.4089	-0.268	-0.2996
Little Swanport River	597	0.9222	0.9164	-0.2493
Londwater River	13.6	0.3079	0.4827	0.2031
Maclaines Creek	62.9	1.0059	1.5280	0.2499
Meander River (Deloraine)	474	0.3588	0.3943	0.1789
Meander River (Warner)	103	0.328	1.178	0.2634
Meander River (Westwood)	1269	0.4497	0.4909	-0.1416
Meredith River	86.4	0.6213	-0.1243	-0.1620
Mersey River	1618	0.5022	0.8221	-0.1037
Montagu River (bridge)	323	0.4260	0.4251	-0.0532
Montagu River (Togari)	142	0.4685	0.3487	0.1380
Mountain River	40	0.4493	0.0834	0.6172
Nive River	186	0.2557	1.068	-0.2212
North Esk	373	0.3964	0.4306	0.2704
North West Bay River	88.2	0.5859	0.3761	-0.3376
Orielton Rivulet	48.2	0.8589	1.1934	0.4144
Pet River	11	0.3951	0.3576	0.0230
Pieman River	2541	0.2679	1.0126	-0.2395

	M.A.R. (mm)	Cv monthly flows	Cv monthly peaks	Cv monthly lows
Gawler River	513	0.8323	0.7117	1.1476
George River	525	0.3990	0.5780	0.4428
Gordon River	1550	0.4277	0.3708	0.5413
Great Musselroe River	286	0.5893	0.5301	0.8980
Hellyer River	1343	0.6227	0.5075	0.6584
Henty River	271	0.4081	0.4108	0.6052
Huon River	1588	0.3544	0.5084	0.5289
Inglis River	765	0.7285	0.6530	0.9067
Iron Creek	139	0.5996	0.5116	2.3690
Jordan River	36	0.9674	0.8997	1.5962
King River	2339	0.3540	0.2654	0.6239
Lake River	446	0.5115	0.4436	1.1079
Leven River	1053	0.6703	0.5070	0.8456
Little Swanport River	121	0.7623	0.7711	1.1153
Londwater River	1203	0.6511	0.5069	0.8980
Maclaines Creek	243	0.5063	0.3853	1.5804
Meander River (Deloraine)	918	0.6381	0.5107	1.2569
Meander River (Warner)	1554	0.5506	0.3515	1.0254
Meander River (Westwood)	492	0.7759	0.6527	1.2096
Meredith River	239	0.6508	0.7256	0.7715
Mersey River	658	0.7085	0.5502	1.1130
Montagu River (bridge)	415	0.9321	0.6975	1.3292
Montagu River (Togari)	427	0.9601	0.6626	0.9321
Mountain River	690	0.3860	0.3662	0.7107
Nive River	1058	0.6080	0.5027	0.8462
North Esk	466	0.6062	0.5213	0.5835
North West Bay River	238	0.6876	0.6921	1.0995
Orielton Rivulet	53	1.0112	1.1076	0.7307
Pet River	845	0.7458	0.5881	0.9224
Pieman River	1566	0.5943	0.4285	0.6219

	Specific peaks $\overline{Q}$ ($m^3/s/km^2$)	Iv log peak flows	g log peak flows
Gawler River	0.3108	0.2056	-0.2709
George River	0.4174	0.3078	0.0276
Gordon River	0.5426	0.1404	0.4284
Great Musselroe River	0.2504	0.2939	-0.6341
Hellyer River	0.3597	0.1836	0.3502
Henty River	1.8737	0.0981	0.3201
Huon River	0.6651	0.2176	-3.2301
Inglis River	0.3202	0.1189	-1.3937
Iron Creek	0.7213	0.5855	-1.3073
Jordan River	0.0715	0.8233	-0.7562
King River	0.6804	0.1540	0.5879
Lake River	0.2586	0.2841	-0.8218
Leven River	0.5190	0.1776	0.6722
Little Swanport River	0.3219	0.6862	-1.9796
Londwater River	0.2980	0.1606	0.0281
Maclaines Creek	0.8178	0.6655	-1.9669
Meander River (Deloraine)	0.4245	0.1233	-1.2009
Meander River (Warner)	1.6222	0.2006	-0.9482
Meander River (Westwood)	0.2041	0.1724	0.6576
Meredith River	1.0102	0.3652	-0.7927
Mersey River	0.2834	0.3706	-0.6470
Montagu River (bridge)	0.1042	0.1475	-1.3354
Montagu River (Togari)	0.1055	0.1847	-1.2855
Mountain River	1.0163	0.3384	-0.8115
Nive River	0.2233	0.1559	0.7742
North Esk	0.1924	0.2407	0.0507
North West Bay River	0.9709	0.3518	0.4039
Orielton Rivulet	0.5158	1.1261	-0.9722
Pet River	0.4316	0.2934	0.0659
Pieman River	0.6857	0.1518	-0.9391

	Iv low flows	Specific lows $\overline{Q}$ $(m^3/s/km^2)x10^{-4}$
Gawler River	0.8485	6.5308
George River	1.1519	14.1877
Gordon River	0.2922	22.00
Great Musselroe River	0.6092	6.3239
Hellyer River	0.4200	38.6765
Henty River	0.2247	47.6034
Huon River	0.1915	42.2362
Inglis River	0.4381	22.2151
Iron Creek	2.0667	0.1582
Jordan River	3.3334	0.0162
King River	0.3848	41.4788
Lake River	0.8393	11.4561
Leven River	0.3583	32.484
Little Swanport River	1.4651	0.072
Londwater River	0.3414	36.3971
Maclaines Creek	2.7143	0.1113
Meander River (Deloraine)	0.7745	8.384
Meander River (Warner)	0.5587	18.7864
Meander River (Westwood)	0.6668	3.1056
Meredith River	1.1406	0.7407
Mersey River	0.3455	12.0958
Montagu River (bridge)	0.4217	4.031
Montagu River (Togari)	1.3509	1.2042
Mountain River	0.7081	25.775
Nive River	1.0947	9.0269
North Esk	0.3726	19.4987
North West Bay River	1.4059	2.2902
Orielton Rivulet	0.00	0.00
Pet River	0.3981	19.1818
Pieman River	0.3266	29.3325

	Catchment area (km^2)	Cv annual flows	Cs annual flows	r_1 annual flows
Pine Tree Rivulet	19.4	0.2546	0.089	0.1210
Pipers River	298	0.4291	-0.1199	0.0474
Prosser River	684	0.7923	0.7307	0.2377
Que River	119	0.2223	0.847	-0.2373
Ringarooma River	482	0.2820	-0.9727	-0.0991
Rubicon River	259	0.6083	1.1574	0.0266
Seabrook Creek	42	0.5556	1.5220	0.1086
Snug River	17.1	0.5201	0.2062	-0.0376
South Esk River	8997	0.3317	0.2189	0.2533
South Esk River	2242	0.6853	2.3037	-0.0722
South Esk River	3280	0.5219	0.802	0.2431
South Pats River	20.6	0.5910	1.3982	0.2826
Sulphur Creek	24.1	0.3317	0.2189	0.2533
Supply River	134	0.7815	1.9076	-0.0879
Swan River	448	0.8150	0.6277	0.1159
Tomahawk River	115	0.4671	0.6189	0.1508
Tyenna River	205	0.2594	0.9804	0.2223
Whyte River	325	0.2614	0.1614	-0.1611

	M.A.R. (mm)	Cv monthly flows	Cv monthly peaks	Cv monthly lows
Pine Tree Rivulet	1637	0.5977	0.4577	1.4471
Pipers River	347	0.8886	0.8397	1.4196
Prosser River	167	0.5943	0.4598	1.7340
Que River	1269	0.5789	0.4824	0.7663
Ringarooma River	644	0.7545	0.8008	0.7633
Rubicon River	270	1.0216	0.7906	2.2573
Seabrook Creek	505	0.7622	0.7766	0.8522
Snug River	286	0.5564	0.5404	0.8345
South Esk River	200	0.6698	0.3875	1.6340
South Esk River	295	0.5306	0.5172	1.2593
South Esk River	271	0.5861	0.3422	1.1485
South Pats River	225	0.6068	0.5073	1.6869
Sulphur Creek	533	0.6029	0.5120	0.6834
Supply River	373	0.9508	0.8714	1.1877
Swan River	343	0.6373	0.5788	0.9832
Tomahawk River	265	0.8522	0.6795	1.5158
Tyenna River	865	0.5030	0.5521	0.5785
Whyte River	1480	0.5239	0.4507	0.6931

	Specific peaks $\overline{Q}$ ($m^3/s/km^2$)	Iv log peak flows	g log peak flows
Pine Tree Rivulet	2.8322	0.1794	-0.2024
Pipers River	0.3538	0.3393	0.0995
Prosser River	0.3805	0.6564	-1.2882
Que River	0.4335	0.1341	0.3700
Ringarooma River	0.2121	0.1762	-0.3516
Rubicon River	0.2037	0.2150	-0.3809
Seabrook Creek	0.2162	0.1418	-1.7726
Snug River	0.6177	0.4956	-1.1855
South Esk River	0.0888	0.2860	0.1991
South Esk River	0.4116	0.3020	-0.3793
South Esk River	0.2102	0.3565	0.0830
South Pats River	0.5161	0.3825	-0.0645
Sulphur Creek	0.1994	0.2076	-0.4322
Supply River	0.3272	0.1848	0.6057
Swan River	1.179	0.6554	-2.4651
Tomahawk River	0.2781	0.1589	-0.5163
Tyenna River	0.1952	0.1976	0.2555
Whyte River	0.6161	0.1345	-0.2812

	Iv low flows	Specific lows $\overline{Q}$ $(m^3/s/km^2)x10^{-4}$
Pine Tree Rivulet	2.7778	0.4639
Pipers River	2.2828	7.4161
Prosser River	1.90	0.2778
Que River	0.2717	24.3697
Ringarooma River	0.2299	27.9149
Rubicon River	1.2000	0.251
Seabrook Creek	0.6590	11.381
Snug River	1.8858	12.807
South Esk River	0.7993	4.0074
South Esk River	0.6722	4.8903
South Esk River	0.6255	3.7232
South Pats River	0.00	0.00
Sulphur Creek	0.4564	28.5477
Supply River	0.3827	4.8358
Swan River	1.5678	0.6094
Tomahawk River	0.9520	1.087
Tyenna River	0.1542	38.761
Whyte River	0.3295	44.0

Appendix 2 Data obtained from the two pluviographs in the upper Swan River catchment

Pluviograph P1 : Mt. St. John at 400m A.S.L.
Installed on 25/7/84

		Precipitation (mm)
25/7/84	– 29/7/84	187
	7/8/84	80
	28/8/84	206
	18/9/84	189
	9/10/84	112
	16/10/84	13
	31/10/84	12
	20/11/84	38.5
	11/12/84	30
	8/1/84	100
	31/1/84	30
	27/12/84	12
	19/3/85	127
	11/4/85	130
	7/5/85	114
	3/6/85	66.6
	30/6/85	62.3
	24/7/85	15.8
	21/8/85	88.2
	22/9/85	87.9
	5/10/85	19.6
	22/10/85	86.6
	3/11/85	46.8
	22/11/85	130.8
	8/12/85	173
	28/12/85	248
	14/1/85	58.8
	31/1/85	66.4
	20/2/86	8.8
	13/3/86	17.8
	10/4/86	42.6
	5/5/86	76.6
	17/5/86	150.4
	13/6/86	10
	27/6/86	23
	24/7/86	163.2
TOTAL		3024.7mm

P2 : Upper Swan at 500m A.S.L
Installed on 17/7/84

		Precipitation (mm)
17/7/84	– 29/7/84	164
	7/8/84	89.5
	28/8/84	209
	18/9/84	144
	9/10/84	85
	31/10/84	17
	20/11/84	36
	11/12/84	30
	8/1/85	108
	30/1/85	19
	27/2/85	9
	19/3/85	100
	11/4/85	85
	30/4/85	102.8
	21/5/85	51
	12/6/85	49
	17/7/85	45
	23/7/85	15
	3/9/85	67
	24/9/85	64
	15/10/85	29
	7/11/85	200
	28/11/85	78.4
	17/12/85	372
	15/1/86	245
	20/2/86	7.4
	13/3/86	16.4
	10/4/86	40.6
	23/7/86	178
TOTAL		2683.1mm

Pluviograph P1 : Mt. St. John at 400m A.S.L.
Installed on 25/7/84

		Precipitation (mm)
25/7/84	- 29/7/84	187
	7/8/84	80
	28/8/84	206
	18/9/84	189
	9/10/84	112
	16/10/84	13
	31/10/84	12
	20/11/84	38.5
	11/12/84	30
	8/1/84	100
	31/1/84	30
	27/12/84	12
	19/3/85	127
	11/4/85	130
	7/5/85	114
	3/6/85	66.6
	30/6/85	62.3
	24/7/85	15.8
	21/8/85	88.2
	22/9/85	87.9
	5/10/85	19.6
	22/10/85	86.6
	3/11/85	46.8
	22/11/85	130.8
	8/12/85	173
	28/12/85	248
	14/1/85	58.8
	31/1/85	66.4
	20/2/86	8.8
	13/3/86	17.8
	10/4/86	42.6
	5/5/86	76.6
	17/5/86	150.4
	13/6/86	10
	27/6/86	23
	24/7/86	163.2
	TOTAL	3024.7mm

P2 : Upper Swan at 500m A.S.L
Installed on 17/7/84

		Precipitation (mm)
17/7/84	- 29/7/84	164
	7/8/84	89.5
	28/8/84	209
	18/9/84	144
	9/10/84	85
	31/10/84	17
	20/11/84	36
	11/12/84	30
	8/1/85	108
	30/1/85	19
	27/2/85	9
	19/3/85	100
	11/4/85	85
	30/4/85	102.8
	21/5/85	51
	12/6/85	49
	17/7/85	45
	23/7/85	15
	3/9/85	67
	24/9/85	64
	15/10/85	29
	7/11/85	200
	28/11/85	78.4
	17/12/85	372
	15/1/86	245
	20/2/86	7.4
	13/3/86	16.4
	10/4/86	40.6
	23/7/86	178
	TOTAL	2683.1mm

APPENDIX 3

Average recurrence interval of particular discharges for the Swan and Apsley Rivers

Rank (i)	Discharge m^3/s	Average recurrence interval (years) T_i
1	1000	19
2	609	9.5
3	461	6.33
4	386	4.75
5	383	3.80
6	375	3.17
7	342	2.71
8	298	2.38
9	257	2.11
10	238	1.90
11	215	1.73
12	211	1.58
13	208	1.46
14	203	1.36
15	197	1.27
16	190	1.19
17	189	1.12
18	187	1.06
19	165	1.00
20	159	0.95
21	157	0.90
22	154	0.86
23	150	0.83
24	140	0.79
25	138	0.76
26	133	0.73
27	130	0.70
28	126	0.68
29	122	0.66
30	120	0.63
31	119	0.61
32	100	0.59
33	93	0.58
34	87	0.56
35	83	0.54
36	78	0.53
37	75	0.51
38	74	0.50
39	71	0.49
40	64	0.48

SWAN RIVER

Rank (i)	Discharge m^3/s	Average recurrence interval (years) T_i
1	594	20
2	213	10
3	173.4	6.67
4	152.6	5
5	140.2	4
6	131.6	3.33
7	121.7	2.86
8	116.5	2.50
9	111.2	2.22
10	110.4	2
11	109.2	1.82
12	106.0	1.67
13	105.4	1.54
14	104.7	1.43
15	94.7	1.33
16	88.6	1.25
17	88.6	1.18
18	86.5	1.11
19	84.3	1.05
20	82.6	1.0
21	82.1	0.95
22	81.5	0.91
23	79.8	0.87
24	75.5	0.83
25	75.5	0.80
26	74.1	0.77
27	72.2	0.74
28	70.4	0.71
29	70.1	0.69
30	70.1	0.67
31	67.4	0.65
32	65.8	0.63
33	64.1	0.61
34	63.0	0.59
35	60.6	0.57
36	60.6	0.56
37	58.9	0.54
38	57.7	0.53
39	53.1	0.51
40	51.2	0.5

APSLEY RIVER

Appendix 4 Permanent plot data: % cover of each species at each time period for plots 1 to 14. With the exception of plot 12, cover is expressed to the nearest whole percent

Plot 1

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	5	5	5	10	10	10	15	10	10	10	15	10	10	15	25	5	10	10
Ruppia polycarpa	15	16	20	15	15	12	-	-	-	-	-	-	5	5	8	3	3	-
Lepilaena cylindriocarpa	10	12	12	13	13	15	8	5	3	3	8	8	5	5	20	10	5	-
Juncus kraussii	10	8	8	8	8	8	8	8	9	9	9	9	9	9	10	12	12	10
Baumea arthrophylla	8	5	5	5	5	5	5	5	5	5	5	5	5	5	5	8	8	8
Potamogeton pectinatus	30	30	20	20	20	20	20	45	45	50	50	45	30	15	10	45	50	60
Eleocharis sphacelata	12	12	12	12	10	10	10	8	8	12	12	12	12	10	10	10	10	12
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera																		
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 2

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	10	10	10	10	10	10	12	12	15	15	15	12	10	8	5	5	5	5
Ruppia polycarpa																		
Lepilaena cylindriocarpa	30	25	22	20	20	22	22	22	22	30	28	25	25	28	30	8	5	-
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus	20	20	20	20	20	22	30	40	40	35	25	25	10	10	10	47	22	50
Eleocharis sphacelata																		
Zostera muelleri	5	5	5	5	3	3	3	5	10	8	8	8	5	5	5	5	-	-
Ruppia megacarpa	25	22	22	22	22	20	20	20	20	22	22	22	20	15	10	10	8	8
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera																		
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 3

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	8	10	12	12	12	10	8	10	10	10	10	10	15	15	15	8	8	10
Ruppia polycarpa																		
Lepilaena cylindriocarpa	10	10	10	10	8	8	3	8	12	12	8	5	5	3	3	-	-	-
Juncus kraussii																		
Baumea arthrophylla												-	2	2	3	3	4	5
Potamogeton pectinatus																		
Eleocharis sphacelata																		
Zostera muelleri	8	8	8	8	8	8	5	5	5	5	5	5	5	5	5	5	5	5
Ruppia megacarpa	10	10	10	10	5	5	5	12	20	20	15	10	8	8	15	5	5	5
Phragmites australis	12	12	12	10	5	5	5	10	10	10	10	10	5	5	8	10	10	10
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera																		
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 4

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	20	20	15	15	12	5	5	5	12	15	15	15	10	10	20	5	5	8
Ruppia polycarpa																		
Lepilaena cylindriocarpa	5	5	-	-	-	-	-	15	25	12	-	-	-	5	18	5	-	-
Juncus kraussii	8	8	8	8	5	5	5	5	5	5	5	5	5	5	5	8	8	10
Baumea arthrophylla																		
Potamogeton pectinatus	12	12	8	8	8	8	8	10	35	30	30	12	10	5	5	20	20	30
Eleocharis sphacelata																		
Zostera muelleri	10	10	10	8	8	5	5	-	-	3	3	5	8	8	8	5	5	5
Ruppia megacarpa	8	8	3	-	-	3	5	5	10	8	8	5	5	5	10	3	5	-
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera																		
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 5

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	6	8	8	6	6	6	5	4	4	8	4	4	4	4	9	9	6	6
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus	–	–	–	–	–	–	–	2	4	6	6	6	4	4	8	6	6	6
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	4	4	6	6	8	6	3	3	2	2	2	1	1	1	2	5	6	6
Potamogeton australiensis												–	–	–	–	1	1	1
Scirpus fluitans	6	6	6	6	6	6	1	1	6	6	4	2	2	2	4	6	4	4
Lilaeopsis brownii	1	2	2	1	1	1	1	1	2	2	2	2	1	1	1	2	2	3
Juncus articulatus	1	4	6	6	5	4	4	4	4	4	6	6	2	2	2	4	4	4
Triglochin procera	1	2	4	4	4	4	4	4	6	8	8	6	6	2	2	2	4	4
Potamogeton ochreatus	2	4	4	6	4	3	3	3	8	8	7	7	3	2	9	6	2	2
Potamogeton perfoliatus	–	–	–	–	–	–	–	1	4	4	4	2	2	2	2	–	–	–
Isotoma fluviatilis												–	–	–	–	–	–	2
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 6

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	5	5	3
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	8	8	8	5	5	5	5	5	5	8	6	5	5	5	5	8	8	3
Potamogeton australiensis	8	8	8	5	5	1	1	1	1	2	2	1	1	1	3	5	2	-
Scirpus fluitans																		
Lilaeopsis brownii	5	5	5	5	5	2	2	3	5	5	5	5	5	3	3	4	4	4
Juncus articulatus	-	-	-	-	-	-	-	-	1	2	2	2	2	2	5	10	10	10
Triglochin procera	10	8	8	8	8	5	5	5	8	8	8	7	5	5	10	5	2	2
Potamogeton ochreatus	8	8	8	8	8	3	3	5	5	6	8	5	5	5	10	5	8	20
Potamogeton perfoliatus	-	-	-	-	-	-	-	-	2	2	3	3	3	3	3	-	-	-
Isotoma fluviatilis																		
Typha orientalis	8	8	8	5	5	5	3	3	3	5	5	4	3	2	2	5	5	3
Gratiola nana	5	5	5	5	3	5	5	5	8	8	6	5	5	5	5	8	8	2
Nitella sp.	10	10	8	5	5	5	3	3	8	12	12	10	5	3	5	15	8	5
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 7

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	10	10	8	8	8	8	1	1	1	2	3	3	2	2	2	1	1	2
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata	5	5	5	4	4	4	2	2	2	2	2	2	1	1	3	1	1	2
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans	10	10	8	6	6	5	2	2	6	6	5	3	3	3	2	2	5	5
Lilaeopsis brownii	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	2	3	1
Juncus articulatus	10	10	10	8	8	5	5	5	6	8	8	8	8	8	8	10	12	12
Triglochin procera	-	-	-	-	-	-	-	-	2	2	3	2	2	2	2	5	5	3
Potamogeton ochreatus																		
Potamogeton perfoliatus	10	10	10	8	8	5	3	2	5	8	10	5	4	5	15	18	8	5
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.	12	12	12	8	3	2	2	2	5	5	3	3	3	3	10	5	3	1
Centipeda minima	3	3	3	3	3	1	1	2	3	2	2	1	1	2	3	1	1	2
Scirpus nodosus	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 8

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum	10	10	10	10	10	10	8	8	10	10	10	5	5	5	10	10	8	5
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus	–	–	–	–	–	–	–	–	1	1	2	3	3	3	5	5	3	5
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis	1	1	1	1	1	1	2	2	8	5	5	3	2	2	5	5	5	8
Scirpus fluitans	5	5	5	5	5	3	1	1	1	2	3	3	3	3	3	3	5	8
Lilaeopsis brownii																		
Juncus articulatus	5	5	3	3	3	3	3	3	5	8	8	5	5	5	3	3	3	3
Triglochin procera	3	3	3	3	3	3	2	2	8	10	10	8	8	8	20	20	20	15
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 9

SPECIES	DATE																	
	1984									1985					1986			
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus	5	4	4	4	5	5	2	2	2	2	2							
Triglochin procera	20	15	15	15	15	15	10	15	15	20	20	15	15	15	15	20	20	20
Potamogeton ochreatus																		
Potamogeton perfoliatus	-	-	-	-	-	-	-	2	5	5	5	5	5	5	12	15	-	-
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum																		
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 10

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta																		
Potamogeton australiensis																		
Scirpus fluitans																		
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera	5	5	5	3	3	3	3	3	5	5	8	8	5	5	8	5	8	5
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans	-	-	-	-	-	-	-	1	1	1	2	1	1	1	1	1	2	1
Myriophyllum pedunculatum												-	-	-	-	2	2	2
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 11

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata	5	5	5	5	1	3	3	3	5	5	5	3	1	1	3	5	5	2
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	10	10	10	10	10	10	5	5	6	8	8	8	5	5	8	8	8	5
Potamogeton australiensis	2	2	2	2	1	1	1	5	8	8	8	8	5	5	10	10	8	2
Scirpus fluitans	10	10	8	8	8	5	5	4	10	10	10	10	8	8	10	10	8	3
Lilaeopsis brownii	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Juncus articulatus	10	8	8	8	8	8	6	5	8	8	8	8	8	8	5	8	8	5
Triglochin procera	8	8	8	8	8	3	5	8	8	10	10	5	5	8	8	8	8	5
Potamogeton ochreatus																		
Potamogeton perfoliatus	-	-	-	-	-	-	1	1	2	2	2	1	1	1	2	2	1	1
Isotoma fluviatilis												-	-	-	1	1	1	1
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	2
Myriophyllum pedunculatum																		
Nymphoides exigua	1	1	1	1	1	1	1	-	-	1	1	1	1	1	1	1	1	1
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 12

SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	0.5	1	1	1	1	2	3	2	4
Potamogeton australiensis																		
Scirpus fluitans	5	5	3	3	3	3	1	1	2	3	3	2	1	1	1	1	1	1
Lilaeopsis brownii																		
Juncus articulatus												-	-	-	-	-	-	2
Triglochin procera	1	2	2	2	1	1	1	1	2	3	4	4	5	5	5	1	1	-
Potamogeton ochreatus																		
Potamogeton perfoliatus												-	-	-	-	1	-	-
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans	3	3	3	3	3	3	1	1	1	1.5	2	1.5	1.5	1.5	1	0.5	1	1
Myriophyllum pedunculatum												-	-	-	-	-	1	-
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 13

SPECIES	DATE																	
	1984									1985					1986			
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata																		
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	10	10	10	10	10	10	10	10	10	10	8	8	8	8	2	2	2	1
Potamogeton australiensis																		
Scirpus fluitans	2	2	3	5	5	5	6	5	5	6	6	6	5	5	3	3	3	2
Lilaeopsis brownii																		
Juncus articulatus																		
Triglochin procera	8	10	10	15	15	15	15	60	50	50	50	30	15	15	5	8	10	2
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum	1	1	2	2	2	2	2	3	3	3	3							
Nymphoides exigua																		
Ranunculus rivularis																		
Villarsia reniformis																		
Gratiola latifolia																		

Plot 14

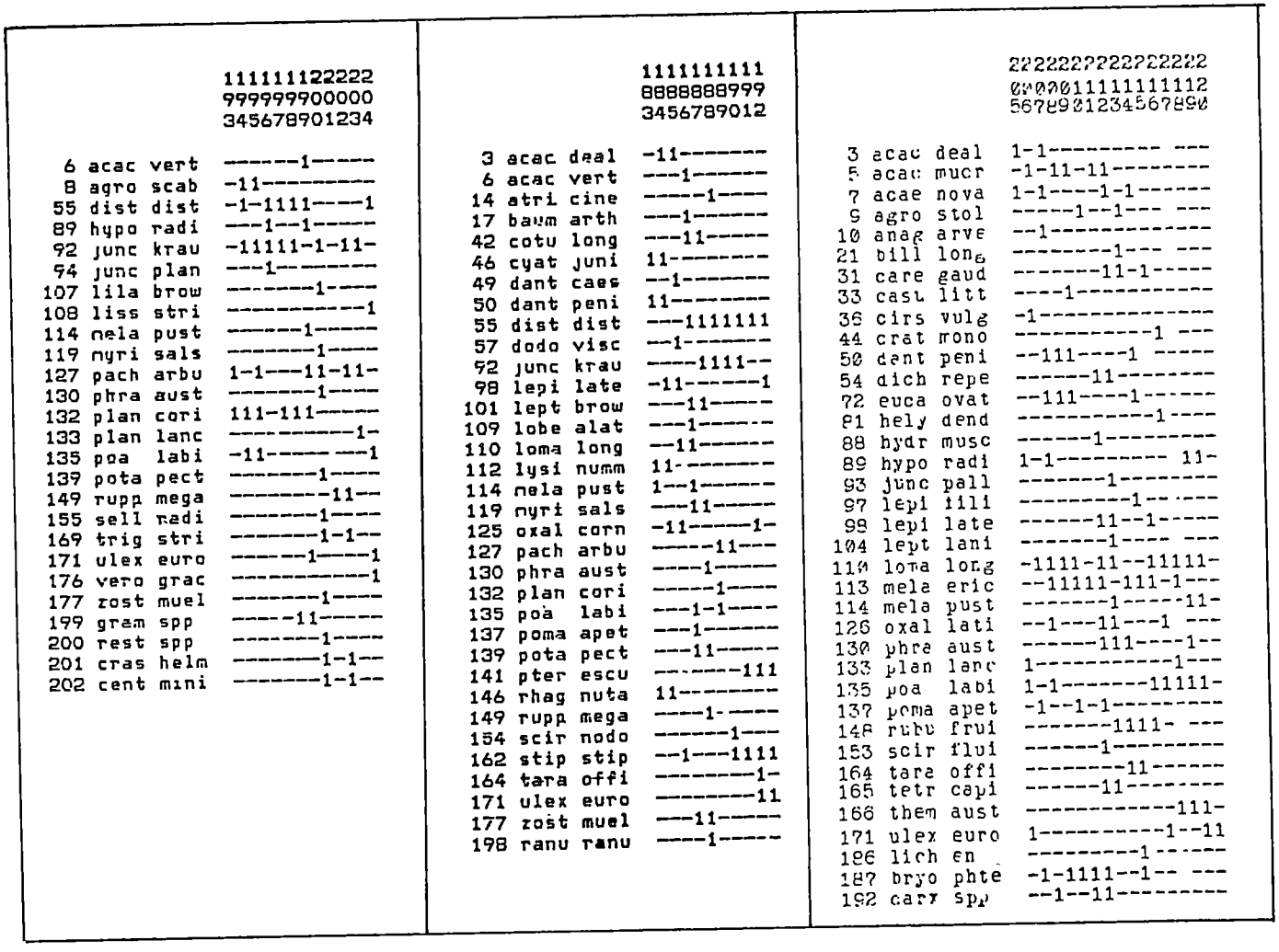
SPECIES	DATE																	
	1984									1985						1986		
	20/2	11/3	10/4	11/5	25/6	20/7	13/8	6/10	2/12	21/1	3/3	22/4	6/6	11/7	14/9	17/1	21/4	1/6
Myriophyllum salsugineum																		
Ruppia polycarpa																		
Lepilaena cylindriocarpa																		
Juncus kraussii																		
Baumea arthrophylla																		
Potamogeton pectinatus																		
Eleocharis sphacelata	6	8	8	8	7	2	2	2	6	7	7	5	5	4	5	5	2	1
Zostera muelleri																		
Ruppia megacarpa																		
Phragmites australis																		
Eleocharis acuta	3	6	6	6	5	2	2	3	4	6	6	4	2	2	4	5	4	2
Potamogeton australiensis																		
Scirpus fluitans	3	4	4	4	5	5	5	4	5	5	6	2	2	3	3	5	4	4
Lilaeopsis brownii	–	–	–	–	–	–	–	2	4	5	6	2	2	2	5	2	1	1
Juncus articulatus																		
Triglochin procera	5	8	8	8	6	6	6	7	8	8	8	6	4	6	8	5	8	5
Potamogeton ochreatus																		
Potamogeton perfoliatus																		
Isotoma fluviatilis																		
Typha orientalis																		
Gratiola nana																		
Nitella sp.																		
Centipeda minima																		
Scirpus nodosus																		
Myriophyllum simulans																		
Myriophyllum pedunculatum	7	8	8	8	6	4	4	3	–	–	–							
Nymphoides exigua																		
Ranunculus rivularis	3	4	6	6	4	2	1	2	4	4	6	2	2	1	3	1	1	1
Villarsia reniformis	–	–	–	–	–	–	–	2	3	4	4	1	1	1	–	2	–	–
Gratiola latifolia	2	7	8	8	6	2	1	1	4	4	6	1	1	3	5	3	1	2

APPENDIX 5

Species list for the Swan and Apsley Rivers.
Tables 1 to 40 display presence/absence data for each species in each quadrat.
The species abbreviations used in the tables do not always resemble the actual names.
Species marked with × were found along the Swan River, and those marked with • found along the Apsley River.

1 Acacia axillaris
2 A. riceana
3 A. dealbata
4 A. genistifolia
5 A. mucronata
6 A. verticillata
7 Acaena novae-zelandiae
8 Agropyron scabrum
9 Agrostis stolonifera
10 Anagallis arvensis ssp. arvensis
11 Aotus ericoides
12 Astroloma humifusum
13 Atherosperma moschatum
14 Atriplex cinerea
15 Baeckea ramosissima
16 Banksia marginata
17 Baumea arthrophylla
18 B. tetragona
19 Bedfordia salicina
20 Beyeria viscosa
21 Billardiera longiflora
22 Blechnum nudum
23 B. wattsii
24 Bursaria spinosa
25 Callistemon pallidus
26 C. paludosus
27 C. viridiflorus
28 Callitris oblonga
29 C. rhomboidea
30 Carex fascicularis
31 Carex gaudichaudiana
32 Cassytha pubescens
33 Casuarina littoralis
34 C. stricta
35 Chara sp.
36 Cirsium vulgare
37 Clematis gentianoides
38 C. microphylla
39 Conium maculatum
40 Coprosma hirtella
41 Correa reflexa
42 Cotula longipes
43 Crassula sieberana
44 Crataegus monogyna
45 Cyathodes divaricata
46 C. juniperina
47 C. parvifolia
48 Cyperus gunnii
49 Danthonia caespitosa
50 D. penicillata
51 D. semiannularis
52 D. setacea
53 Deschampsia caespitosa
54 Dichondra repens
55 Distichlis distichophylla
56 Dodonaea ericifolia
57 D. viscosa
58 Echinopogon ovatus
59 Elatine gratioloides
60 Eleocharis acuta
61 E. gracilis
62 E. sphacelata
63 Epilobium billardierianum
64 Epacris gunnii
65 E. impressa
66 E. lanuginosa
67 E. sp. (possibly E. apsleyensis)
68 E. tasmanica
69 Eucalyptus amygdalina
70 E. globulus
71 E. obliqua
72 E. ovata
73 E. pulchella
74 E. viminalis
75 Exocarpos cupressiformis
76 Gahnia grandis
77 Grevilea australis
78 Hakea lissosperma
79 H. microcarpa
80 Haloragis teucroides
81 Helichrysum dendroideum
82 H. semipapposum
83 Hibbertia riparia
84 Holcus lanatus
85 Hovea heterophylla
86 H. longifolia
87 Hydrocotyle javanica
88 H. muscosa
89 Hypochaeris radicata
90 Isotoma fluviatilis
91 Juncus articulatus
92 J. kraussii
93 J. pallidus
94 J. planifolius
95 J. sandwithii
96 Lasiopetalum micrantheum
97 Lepidosperma filiforme
98 L. laterale
99 L. lineare var. inops
100 Lepileana bilocularis
101 Leptocarpus brownii
102 L. tenex
103 Leptospermum grandiflorum
104 L. lanigerum
105 L. scoparium
106 Leucopogon collinus
107 Lilaeopsis brownii
108 Lissanthe strigosa
109 Lobelia alata
110 Lomandra longifolia
111 Lomatia tinctoria
112 Lysimachia nummularia
113 Melaleuca ericifolia
114 M. pustulata
115 M. squarosa
116 Micrantheum hexandr um
117 Myriophyllum pedunculatum
118 M. simulans
119 M. salsugineum
120 Nitella sp.
121 Notelaea ligustrina
122 Nymphoides exigua
123 Olearia argophylla
124 O. lirata
125 Oxalis corniculata
126 O. latifolia
127 Sclerostegia arbuscula
128 Veronica formosa
129 Phalaris minor
130 Phragmites australis
131 Pittosporum bicolor
132 Plantago coronopus
133 P. lanceolata
134 Poa gunnii
135 P. labillardieri
136 P. poiformis
137 Pomaderris apetala
138 P. elliptica
139 Potomogeton pectinatus
140 P. perfoliatus
141 Pteridium esculentum
142 Pultenaea gunnii
143 P. juniperina
144 Ranunculus rivularis
145 Rhagodia baccata
146 R. nutans
147 Rosa canina
148 Rubus fruticosus
149 Ruppia megacarpa
150 Salix alba x fragilis

151 Schoenus fluitans
152 Scirpus caldwellii
153 S. fluitans
154 S. nodosus
155 Selliera radicans
156 Senecio jacobaea
157 S. quadridentatus
158 Sporobolus virginicus? (or sp. 55)
159 Spyridium microphyllum
160 S. obovatum var. obovatum
161 S. obovatum var. velutinum
162 Stipa sp.
163 Stylidium graminifolium
164 Taraxacum officinale
165 Tetraria capillaris
166 Themeda australis
167 Trifolium repens
168 Triglochin procera
169 T. striata
170 Typha domingensis
171 Ulex europaeus
172 Uncinia
173 Utricularia australis
174 U. dichotoma
175 Veronica formosa
176 V. gracilis
177 Zostera muelleri
178 Schoenus apogon
179 Asperula subsimplex
180 Villarsia reniformis
181 Hypericum japonicum
182 Asperula conferta var. scoparioides
183 Juncus holoschoenus
184 Carex appressa
185 Adiantum aethiopicum
186 Lichen sp.
187 Bryophyte sp.
188 Fern sp.
189 Senecio sp.
190 Rumex sp.
191 Juncus sp.
192 Carex sp.
193 Scirpus aucklandicus
194 Linum marginale
195 Lepilaena australis
196 Spyridium parvifolium
197 Bauera ruboides
198 Ranunculus sp.
199 Graminoid sp.
200 Restio sp.
201 Crassula helmsii
202 Centipeda minima
203 Pultanaea
204 Melaleuca gibbosa
205 Odixia angusta
206 Hakea epiglottis
207 Olearia glandulosa
208 Rumex bidens
209 Acacia melanoxylon
210 Gratiola latifolia
211 Phebalium squameum subsp. retusum
212 Helichrysum bicolor
213 Agropyron pectinatum
214 Aristotelia peduncularis
215 Acacia mearnsii
216 Coprosma quadrifida
217 Festuca arundinacea
218 Scirpus nodosus
219 Dillwynia glaberrima
220 Epacris obtusifolia
221 Comesperma retusum
222 Acacia botrycephala
223 Diplarrena moraea
224 Gonocarpus tetragynus
225 Hydrocotyle pterocarpa
226 Centella cordifolia
227 Lotus pedunculatus
228 Trochocarpa gunnii
229 Plantago varia
230 Lepidosperma longitudinale
231 Melaleuca squamea
232 Neopaxia australasica
233 Polygonum hydropiper
234 Lotus corniculatus
235 Platylobium triangulare
236 Pomaderris pilifera
237 Zieria arborescens
238 Stipa aphylla
239 Cryptandra amara
240 Restio monocephalus
241 Boronia pilosa
242 Spyridium obcordatum
243 Leptospermum riparium
244 Pimelea pauciflora
245 Baumea juncea
246 Pultanaea stricta
247 Olearia ramulosa
248 Acrotriche serrulata
249 Eucalyptus pauciflora
250 Polygonum decipiens
251 Potamogeton ochreatus
252 Typha orientalis

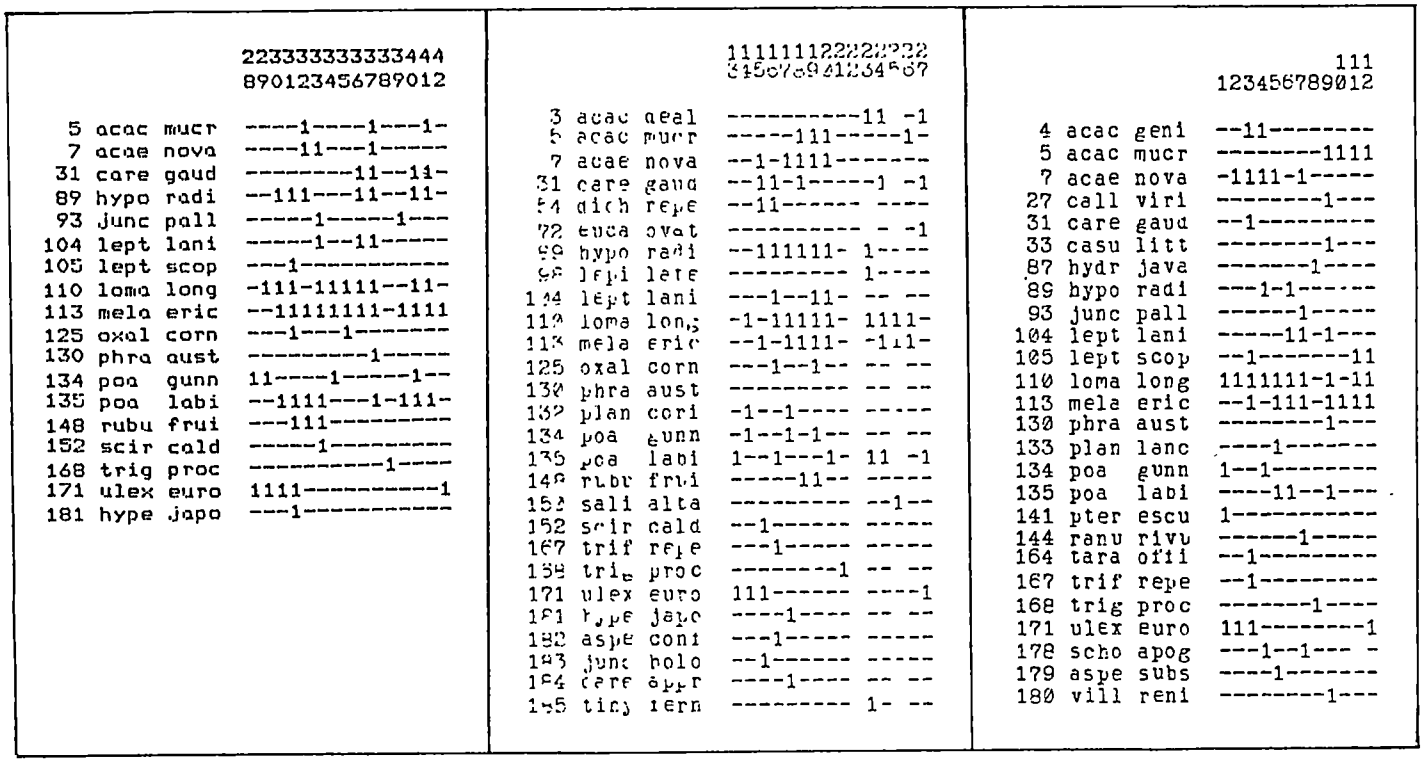


Swan River

Transect 1

Transect 2

Transect 3

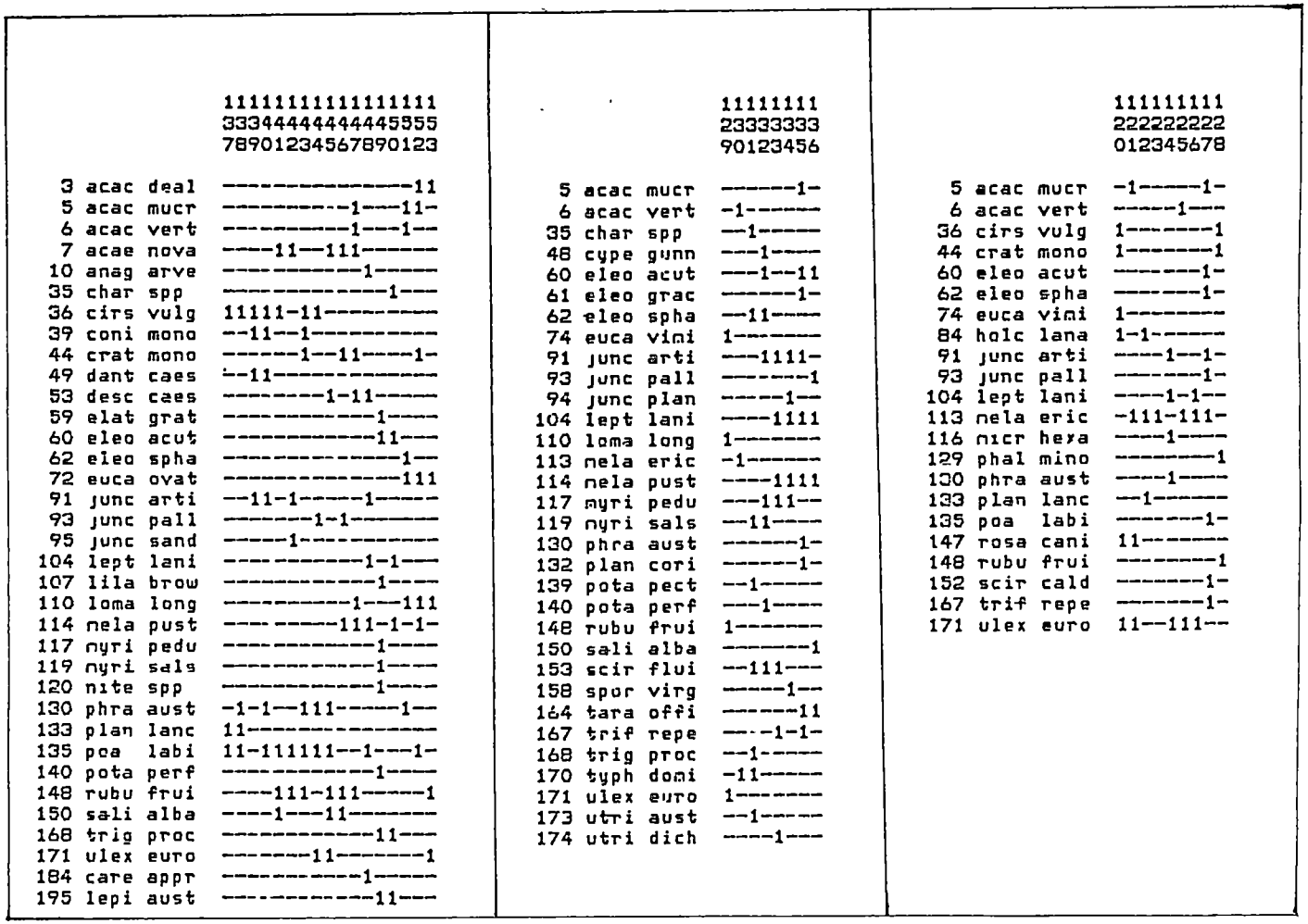


```
                    223333333333444
                    8901234567890l2

  5 acac mucr       ----1----1---1-
  7 acae nova       ----11---1-----
 31 care gaud       --------11--11-
 89 hypo radi       --111---11--11-
 93 junc pall       -----1-----1---
104 lept lani       -----1--11-----
105 lept scop       ---1-----------
110 loma long       -111-11111--11-
113 mela eric       --11111111-1111
125 oxal corn       ---1---1-------
130 phra aust       ---------1-----
134 poa  gunn       11----1-----1--
135 poa  labi       --1111---1-111-
148 rubu frui       ---111---------
152 scir cald       -----1---------
168 trig proc       ----------1----
171 ulex euro       1111----------1
181 hype japo       ---1-----------
```

```
                    1111111222222222
                    345c7c9412345867

  3 acac aeal       ----------11 -1
  5 acac mucr       -----111-----1-
  7 acae nova       --1-1111-------
 31 care gaud       --11-1-----1 -1
 54 dich repe       --11------ ----
 72 euca ovat       ---------- - -1
 89 hypo radi       --111111- 1----
 98 lepi lere       --------- 1----
104 lept lani       ---1--11- -- --
110 loma long       -1-11111- 1111-
113 mela eric       --1-1111- -1-1-
125 oxal corn       ---1--1-- -- --
130 phra aust       --------- -- --
133 plan cori       -1--1---- -----
134 poa  gunn       -1--1-1-- -- --
135 poa  labi       1--1---1- 11 -1
148 rubu frui       -----11-- -----
152 sali alta       --------- --1--
152 scir cald       --1------ -----
167 trif repe       ---1----- -----
168 trig proc       --------1 -- --
171 ulex euro       111------ ----1
181 hype japo       ----1---- -- --
182 aspe coni       ---1----- -----
183 junc holo       --1------ -----
184 cere appr       ----1---- -- --
185 tinj tern       --------- 1- --
```

```
                        111
                    123456789012

  4 acac geni       --11--------
  5 acac mucr       --------1111
  7 acae nova       -1111-1-----
 27 call viri       --------1---
 31 care gaud       --1---------
 33 casu litt       --------1---
 87 hydr java       -------1----
 89 hypo radi       ---1-1------
 93 junc pall       ------1-----
104 lept lani       -----11-1---
105 lept scop       --1-------11
110 loma long       1111111-1-11
113 mela eric       --1-111-1111
130 phra aust       --------1---
133 plan lanc       ----1-------
134 poa  gunn       1--1--------
135 poa  labi       ----11--1---
141 pter escu       1-----------
144 ranu rivu       ------1-----
164 tara offi       --1---------
167 trif repe       --1---------
168 trig proc       -------1----
171 ulex euro       111--------1
178 scho apog       ---1--1--- -
179 aspe subs       ----1-------
180 vill reni       --------1---
```

Transect 4 Transect 5 Transect 6



		1111111111111111 3334444444444555 7890123456789012
3	acac deal	---------------11
5	acac mucr	----------1---11-
6	acac vert	----------1---1--
7	acae nova	----11---111------
10	anag arve	----------1------
35	char spp	----------1---
36	cirs vulg	11111-11----------
39	coni mono	--11--1----------
44	crat mono	------1--11----1-
49	dant caes	--11----------
53	desc caes	--------1-11-----
59	elat grat	----------1-----
60	eleo acut	----------11----
62	eleo spha	----------1---
72	euca ovat	----------111
91	junc arti	--11-1-----1-----
93	junc pall	-------1-1-------
95	junc sand	-----1----------
104	lept lani	----------1-1---
107	lila brow	----------1-----
110	loma long	----------1---111
114	nela pust	---- -----111-1-1-
117	nyri pedu	----------1-----
119	nyri sals	----------1-----
120	nite spp	----------1-----
130	phra aust	-1-1---111-----1--
133	plan lanc	11----------
135	poa labi	11-111111--1---1-
140	pota perf	----------1-----
148	rubu frui	----111-111-----1
150	sali alba	----1---11-------
168	trig proc	----------11----
171	ulex euro	-------11-------1
184	care appr	----------1------
195	lepi aust	---------11----

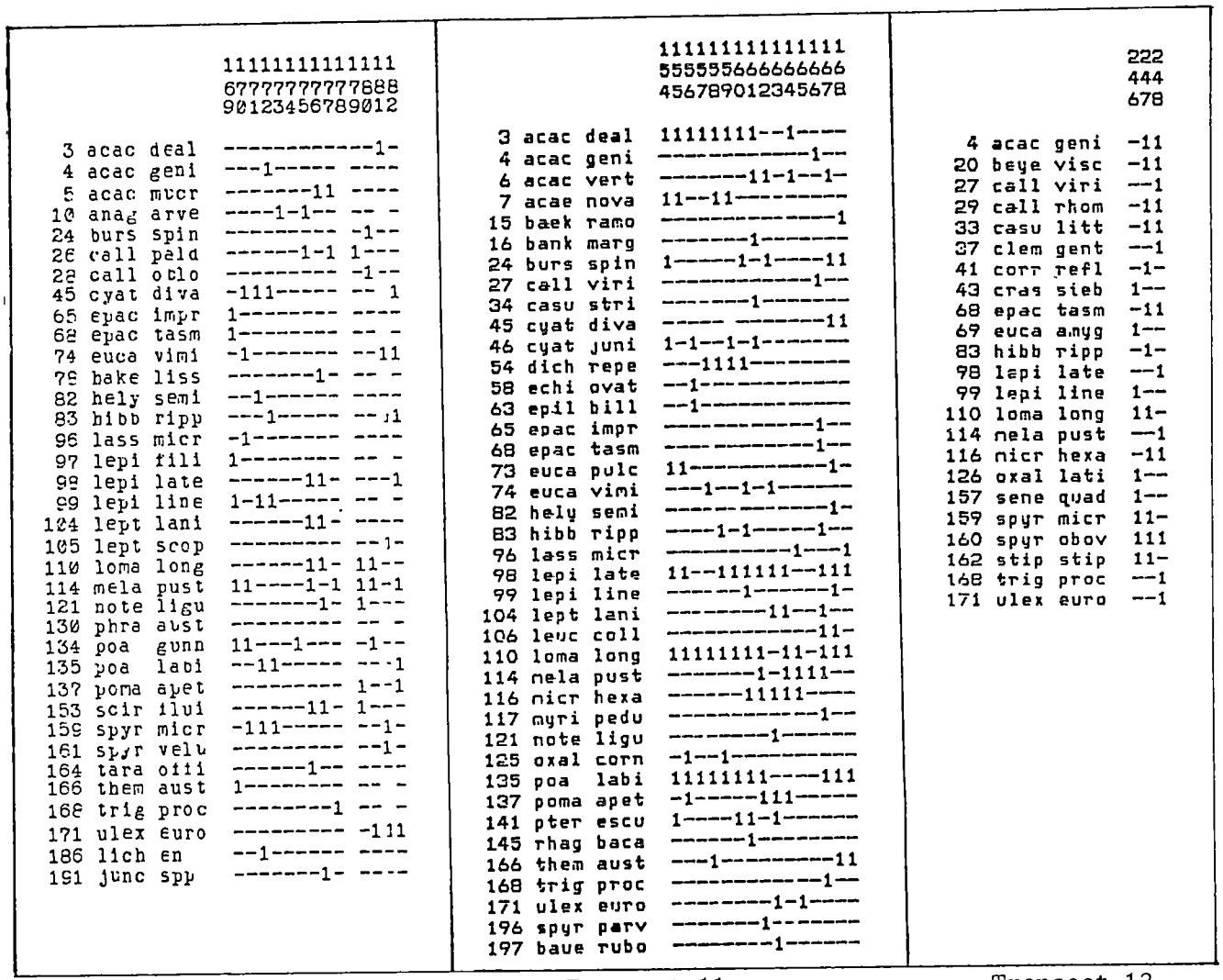
Transect 7

		11111111 23333333 90123456
5	acac mucr	------1-
6	acac vert	-1------
35	char spp	---1-----
48	cype gunn	---1----
60	eleo acut	---1--11
61	eleo grac	------1-
62	eleo spha	--11----
74	euca vimi	1-------
91	junc arti	---1111-
93	junc pall	-------1
94	junc plan	-----1--
104	lept lani	----1111
110	loma long	1-------
113	nela eric	-1------
114	nela pust	----1111
117	myri pedu	---111--
119	nyri sals	--11----
130	phra aust	------1-
132	plan cori	------1-
139	pota pect	--1-----
140	pota perf	---1----
148	rubu frui	1-------
150	sali alba	-------1
153	scir flui	--111---
158	spar virg	-----1--
164	tara offi	------11
167	trif repe	---1-1-
168	trig proc	--1-----
170	typh domi	-11-----
171	ulex euro	1-------
173	utri aust	--1-----
174	utri dich	----1---

Transect 8

		111111111 222222222 012345678
5	acac mucr	-1-----1-
6	acac vert	-----1---
36	cirs vulg	1-------1
44	crat mono	1-------1
60	eleo acut	-------1-
62	eleo spha	-------1-
74	euca vimi	1--------
84	holc lana	1-1------
91	junc arti	----1--1-
93	junc pall	-------1-
104	lept lani	----1-1--
113	nela eric	-111-111-
116	nicr hexa	----1----
129	phal mino	-------1
130	phra aust	----1----
133	plan lanc	--1------
135	poa labi	-------1-
147	rosa cani	11-------
148	rubu frui	-------1
152	scir cald	-------1-
167	trif repe	-------1-
171	ulex euro	11--111--

Transect 9



Transect 10

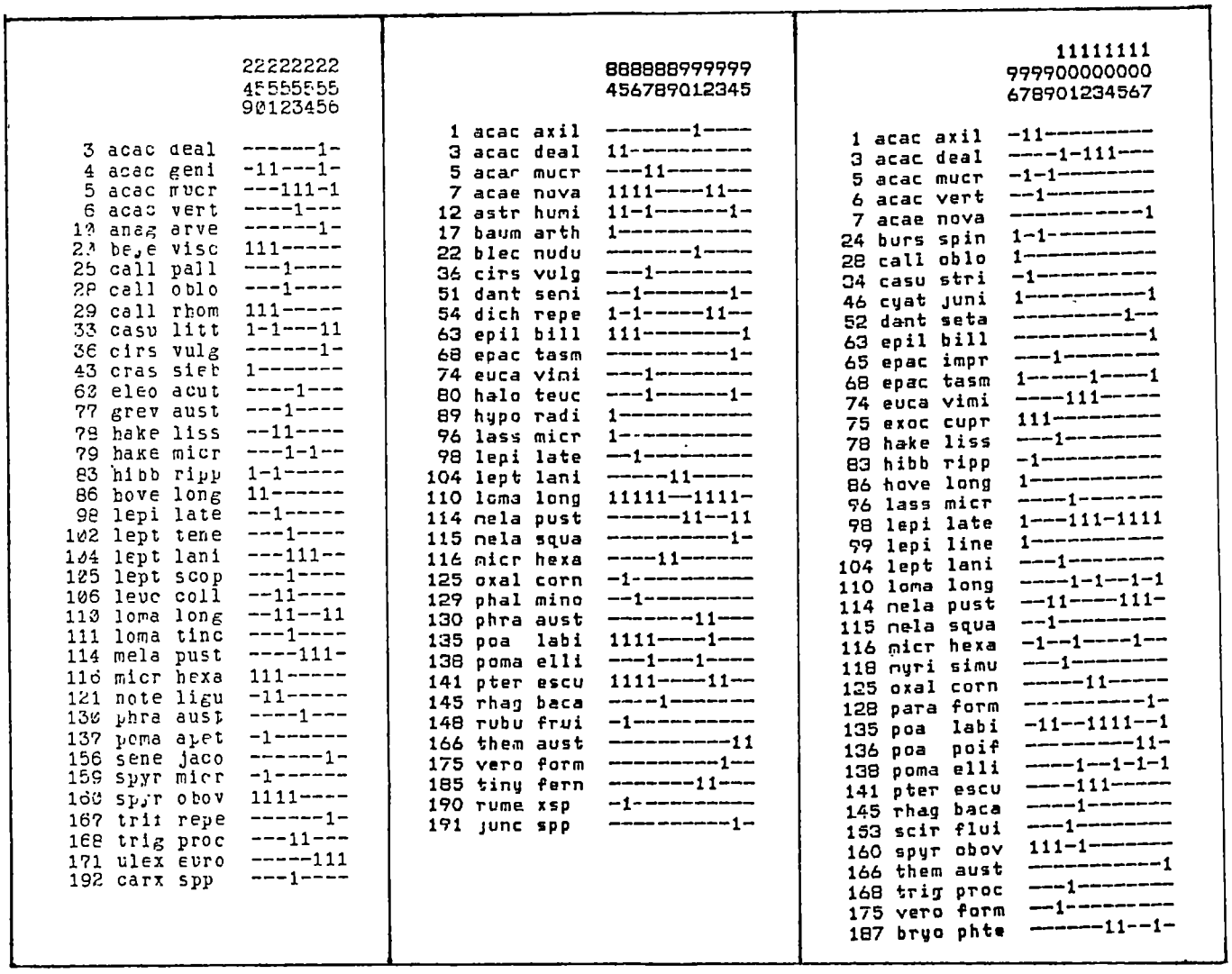
```
                 11111111111111
                 67777777777888
                 90123456789012

  3 acac deal    ------------1-
  4 acac geni    ---1------ ----
  5 acac mucr    --------11 ----
 10 anag arve    ----1-1--- -- -
 24 burs spin    ---------- -1--
 26 call pald    ------1-1 1----
 22 call oblo    ---------- -1--
 45 cyat diva    -111------ -- 1
 65 epac impr    1--------- ----
 62 epac tasm    1--------- -- -
 74 euca vimi    -1-------- --11
 79 hake liss    --------1- -- -
 82 hely semi    --1------- ----
 83 hibb ripp    ---1------ --:1
 96 lass micr    -1-------- ----
 97 lepi fili    1--------- -- -
 98 lepi late    ------11-- ---1
 99 lepi line    1-11------ -- -
104 lept lani    ------11-- ----
105 lept scop    ---------- --1-
110 loma long    ------11-- 11--
114 mela pust    11----1-1 11-1
121 note ligu    --------1- 1---
130 phra aust    ---------- -- -
134 poa  gunn    11---1---- -1--
135 poa  labi    --11------ ---1
137 poma apet    ---------- 1--1
153 scir ilui    ------11-- 1---
159 spyr micr    -111------ --1-
161 spyr velu    ---------- --1-
164 tara oiii    ------1--- ----
166 them aust    1--------- -- -
168 trig proc    --------1 -- -
171 ulex euro    ---------- -111
186 lich en      --1------- ----
191 junc spp     --------1- ----
```

Transect 11

```
                 11111111111111
                 55555566666666
                 45678901234567B

  3 acac deal    11111111--1----
  4 acac geni    ------------1--
  6 acac vert    --------11-1--1-
  7 acae nova    11--11----------
 15 baek ramo    --------------1
 16 bank marg    --------1-------
 24 burs spin    1------1-1-----11
 27 call viri    ------------1--
 34 casu stri    --------1-------
 45 cyat diva    ------ --------11
 46 cyat juni    1-1--1-1--------
 54 dich repe    ---1111---------
 58 echi ovat    --1-------------
 63 epil bill    --1-------------
 65 epac impr    ------------1---
 68 epac tasm    ------ --------1--
 73 euca pulc    11------------1-
 74 euca vimi    ---1--1-1-------
 82 hely semi    ------ --------1-
 83 hibb ripp    -----1-1------1--
 96 lass micr    ----------1----1
 98 lepi late    11--111111--111
 99 lepi line    ------1-------1-
104 lept lani    ---------11--1--
106 leuc coll    ------------11-
110 loma long    11111111-11-111
114 mela pust    --------1-1111--
116 micr hexa    ------11111-----
117 myri pedu    ------------1---
121 note ligu    ----------1------
125 oxal corn    -1--1-----------
135 poa  labi    11111111----111
137 poma apet    -1------111-----
141 pter escu    1----11-1-------
145 rhag baca    -------1--------
166 them aust    ---1----------11
168 trig proc    ------------1---
171 ulex euro    ---------1-1----
196 spyr parv    -------1--------
197 baue rubo    ---------1-------
```

Transect 12

```
                 222
                 444
                 678

  4 acac geni    -11
 20 beye visc    -11
 27 call viri    --1
 29 call rhom    -11
 33 casu litt    -11
 37 clem gent    --1
 41 corr refl    -1-
 43 cras sieb    1--
 68 epac tasm    -11
 69 euca amyg    1--
 83 hibb ripp    -1-
 98 lepi late    --1
 99 lepi line    1--
110 loma long    11-
114 mela pust    --1
116 micr hexa    -11
126 oxal lati    1--
157 sene quad    1--
159 spyr micr    11-
160 spyr obov    111
162 stip stip    11-
168 trig proc    --1
171 ulex euro    --1
```



		22222222 45555555 90123456
3	acac deal	-------1-
4	acac geni	-11---1-
5	acac mucr	---111-1
6	acac vert	----1---
19	anag arve	------1-
23	bere visc	111-----
25	call pall	---1----
28	call oblo	---1----
29	call rhom	111-----
33	casu litt	1-1---11
36	cirs vulg	------1-
43	cras sieb	1-------
62	eleo acut	----1---
77	grev aust	---1----
78	hake liss	--11----
79	hake micr	---1-1--
83	hibb ripp	1-1-----
86	hove long	11------
98	lepi late	--1-----
102	lept tene	---1----
104	lept lani	---111--
105	lept scop	---1----
106	leuc coll	--11----
110	loma long	--11--11
111	loma tinc	---1----
114	mela pust	----111-
116	micr hexa	111-----
121	note ligu	-11-----
130	phra aust	----1---
137	poma apet	-1------
156	sene jaco	------1-
159	spyr micr	-1------
160	spyr obov	1111----
167	trii repe	------1-
168	trig proc	---11---
171	ulex euro	-----111
192	carx spp	---1----

Transect 13

		888888999999 456789012345
1	acac axil	--------1----
3	acac deal	11----------
5	acac mucr	---11-------
7	acae nova	1111----11--
12	astr humi	11-1------1-
17	baum arth	1----------
22	blec nudu	-------1----
36	cirs vulg	---1--------
51	dant seni	--1-------1-
54	dich repe	1-1-----11--
63	epil bill	111--------1
68	epac tasm	----------1-
74	euca vimi	---1--------
80	halo teuc	---1------1-
89	hypo radi	1----------
96	lass micr	1----------
98	lepi late	--1---------
104	lept lani	-----11-----
110	loma long	11111--1111-
114	mela pust	------11--11
115	mela squa	----------1-
116	micr hexa	----11------
125	oxal corn	-1----------
129	phal mino	--1---------
130	phra aust	-------11---
135	poa labi	1111-----1---
138	poma elli	---1---1----
141	pter escu	1111----11--
145	rhag baca	----1-------
148	rubu frui	-1----------
166	them aust	----------11
175	vero form	---------1--
185	tiny fern	-------11---
190	rume xsp	-1----------
191	junc spp	----------1-

Transect 14

		11111111 999900000000 678901234567
1	acac axil	-11---------
3	acac deal	----1-111---
5	acac mucr	-1-1--------
6	acac vert	--1---------
7	acae nova	----------1
24	burs spin	1-1---------
28	call oblo	1----------
34	casu stri	-1----------
46	cyat juni	1---------1
52	dant seta	---------1--
63	epil bill	----------1
65	epac impr	---1--------
68	epac tasm	1-----1----1
74	euca vimi	----111-----
75	exoc cupr	111---------
78	hake liss	---1--------
83	hibb ripp	-1----------
86	hove long	1----------
96	lass micr	----1-------
98	lepi late	1---111-1111
99	lepi line	1----------
104	lept lani	---1--------
110	loma long	----1-1--1-1
114	mela pust	--11----111-
115	mela squa	--1---------
116	micr hexa	-1--1----1--
118	myri simu	---1--------
125	oxal corn	-----11-----
128	para form	----------1-
135	poa labi	-11--1111--1
136	poa poif	---------11-
138	poma elli	----1--1-1-1
141	pter escu	---111------
145	rhag baca	----1-------
153	scir flui	---1--------
160	spyr obov	111-1-------
166	them aust	----------1
168	trig proc	---1--------
175	vero form	--1---------
187	bryo phte	------11--1-

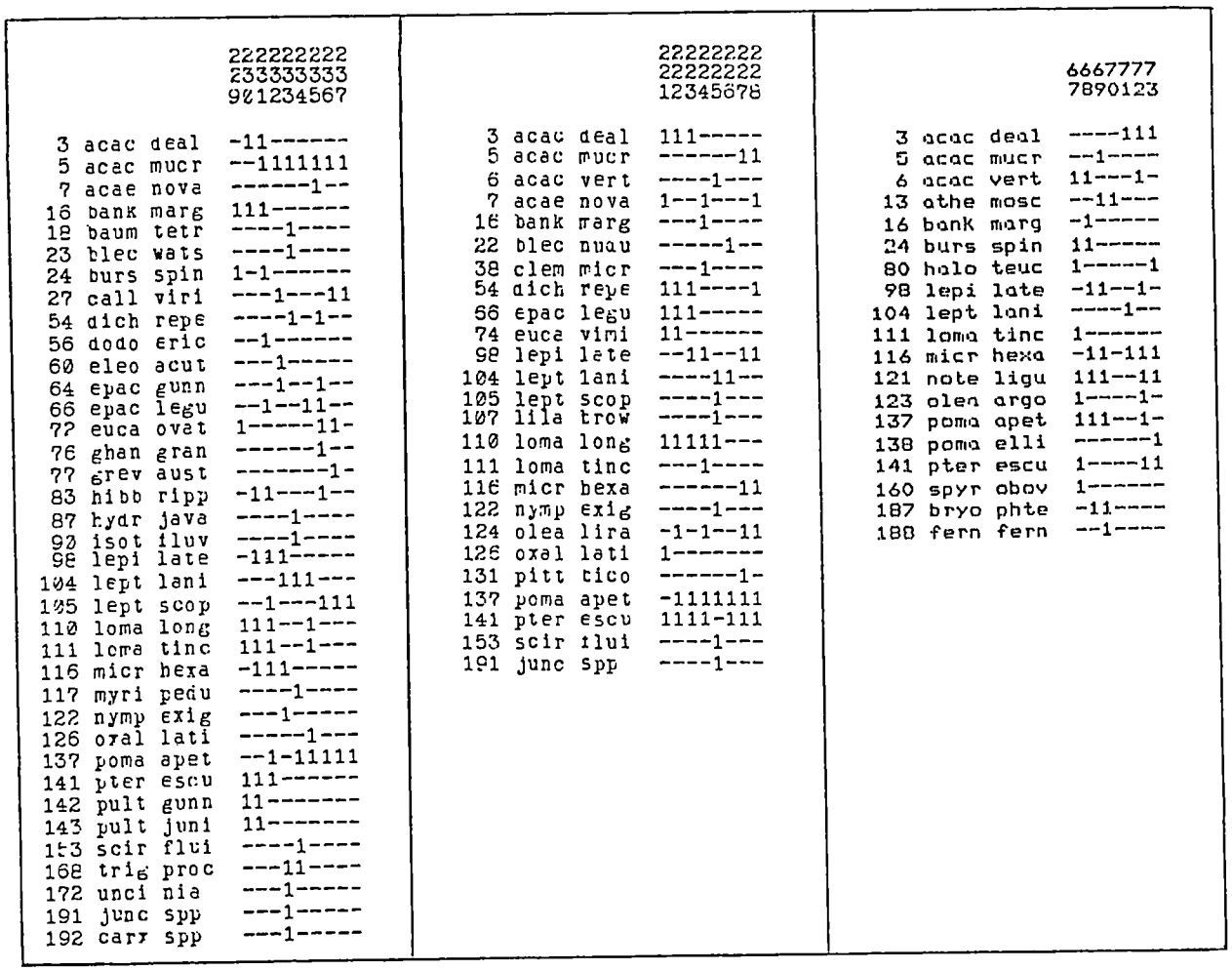
Transect 15

		111111111111 001111111111 890123456789
1	acac axil	---111------
2	acac rice	----1----1--
3	acac deal	-1---1------
5	acac mucr	------1-- --
7	acae nova	----11--- --
19	bedf sali	-----1--- --
20	beye visc	-----1--- --
24	burs spin	--------- 1-
25	call pall	--------- --
29	call rhom	--------- --
30	care fasc	-1------- --
51	dant semi	1-1------ --
54	dich repe	-11------ --
60	eleo acut	-------1- --
63	epil till	----1---- --
68	epac tasm	--------- --
73	euca pulc	--1------ --
74	euca vimi	-1---1--- --
78	hake liss	--------- --
80	halo teuc	1-------- --
83	hibb ripp	-1------- --
87	hydr java	---1----- --
93	junc pall	--------1 --
97	lepi tili	1-------- --
98	lepi late	-11111--- --
103	lept gran	------1-1 --
104	lept lani	-------11 --
105	lept scop	------1-- --
108	liss stri	11------- 1-
110	loma long	--1-1---- --
114	mela pust	1--1-11-1 11
116	micr hexa	-----11-- --
125	oxal corn	---1----- --
135	poa labi	-11-1-1-- --
138	poma elli	----11--- --
141	pter escu	1-111---- --
153	scir flui	--------- --
158	spor virg	---1----- --
160	spyr obov	-----1--- 11
168	trig proc	-------11 --
185	tiny fern	--11----- --
187	bryo phte	----1---- --
192	carx spp	1-------- --
193	scir spp	1-------- --
194	linu marg	-1------- --

Transect 16

		22222222 33444444 89012345
3	acac deal	11------
5	acac mucr	-11-111-
19	bedf sali	11----11
21	bill long	-11----1
24	burs spin	-1---1--
40	copr hert	11----1-
41	corr refl	------1-
43	cras sieb	-------1
45	cyat diva	-1------
67	epac pall	----1---
68	epac tasm	-------1
70	euca glob	------1-
71	euac obli	1-------
76	ghan gran	-----1--
79	hake micr	----1---
85	hove bete	------11
98	lepi late	--11----
104	lept lani	---111--
111	loma tinc	1-------
116	micr hexa	-111111-
121	note ligu	-111-111
122	nymp exig	---1----
128	para form	------11
141	pter escu	-1------
151	scho flui	----1---
153	scir flui	---1----
160	spyr obov	-------1
168	trig proc	---11---

Transect 17



		222222222 233333333 901234567
3	acac deal	-11------
5	acac mucr	--1111111
7	acae nova	------1--
16	bank marg	111------
18	baum tetr	----1----
23	blec wats	----1----
24	burs spin	1-1------
27	call viri	---1---11
54	dich repe	----1-1--
56	dodo eric	--1------
60	eleo acut	---1-----
64	epac gunn	---1--1--
66	epac legu	--1--11--
72	euca ovat	1-----11-
76	ghan gran	------1--
77	grev aust	-------1-
83	hibb ripp	-11---1--
87	hydr java	----1----
90	isot iluv	----1----
98	lepi late	-111-----
104	lept lani	---111---
105	lept scop	--1---111
110	loma long	111--1---
111	loma tinc	111--1---
116	micr hexa	-111-----
117	myri pedu	----1----
122	nymp exig	---1-----
126	oxal lati	-----1---
137	poma apet	--1-11111
141	pter escu	111------
142	pult gunn	11-------
143	pult juni	11-------
153	scir flui	----1----
168	trig proc	---11----
172	unci nia	---1-----
191	junc spp	---1-----
192	carx spp	---1-----

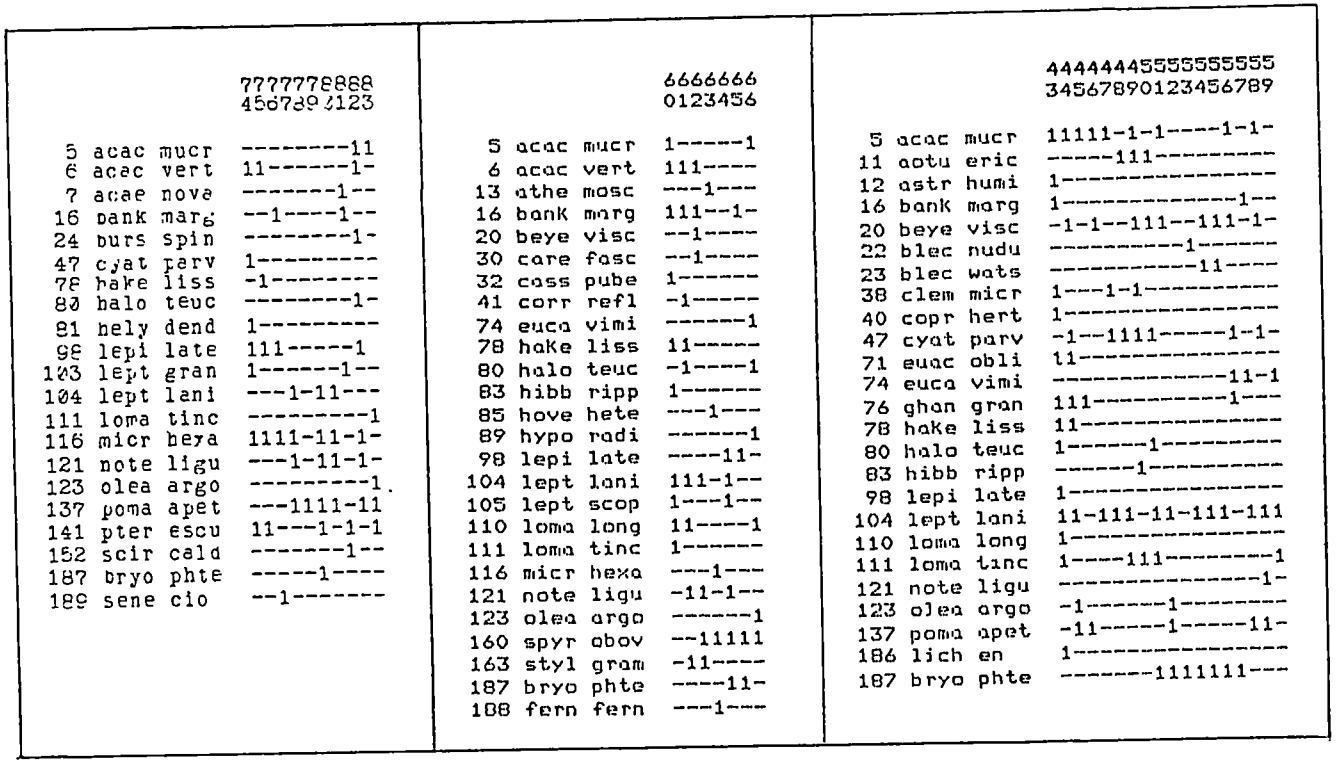
Transect 18

		22222222 22222222 12345678
3	acac deal	111-----
5	acac mucr	------11
6	acac vert	----1---
7	acae nova	1--1---1
16	bank marg	---1----
22	blec nuau	-----1--
38	clem micr	---1----
54	dich repe	111----1
66	epac legu	111-----
74	euca vimi	11------
98	lepi late	--11--11
104	lept lani	----11--
105	lept scop	----1---
107	lila trow	----1---
110	loma long	11111---
111	loma tinc	---1----
116	micr hexa	------11
122	nymp exig	----1---
124	olea lira	-1-1--11
126	oxal lati	1-------
131	pitt tico	------1-
137	poma apet	-1111111
141	pter escu	1111-111
153	scir flui	----1---
191	junc spp	----1---

Transect 19

		6667777 7890123
3	acac deal	----111
5	acac mucr	--1----
6	acac vert	11---1-
13	athe mosc	--11---
16	bank marg	-1-----
24	burs spin	11-----
80	halo teuc	1-----1
98	lepi late	-11--1-
104	lept lani	----1--
111	loma tinc	1------
116	micr hexa	-11-111
121	note ligu	111--11
123	olea argo	1----1-
137	poma apet	111--1-
138	poma elli	------1
141	pter escu	1----11
160	spyr obov	1------
187	bryo phte	-11----
188	fern fern	--1----

Transect 20



		7777778888 4567890123
5	acac mucr	--------11
6	acac vert	11------1-
7	acae nove	-------1--
16	bank marg	--1----1--
24	burs spin	--------1-
47	cyat parv	1---------
78	hake liss	-1---------
80	halo teuc	--------1-
81	hely dend	1---------
98	lepi late	111-----1
103	lept gran	1------1--
104	lept lani	---1-11---
111	loma tinc	---------1
116	micr hexa	1111-11-1-
121	note ligu	---1-11-1-
123	olea argo	---------1
137	poma apet	---1111-11
141	pter escu	11---1-1-1
152	scir cald	-------1--
187	bryo phte	-----1----
189	sene cio	--1-------

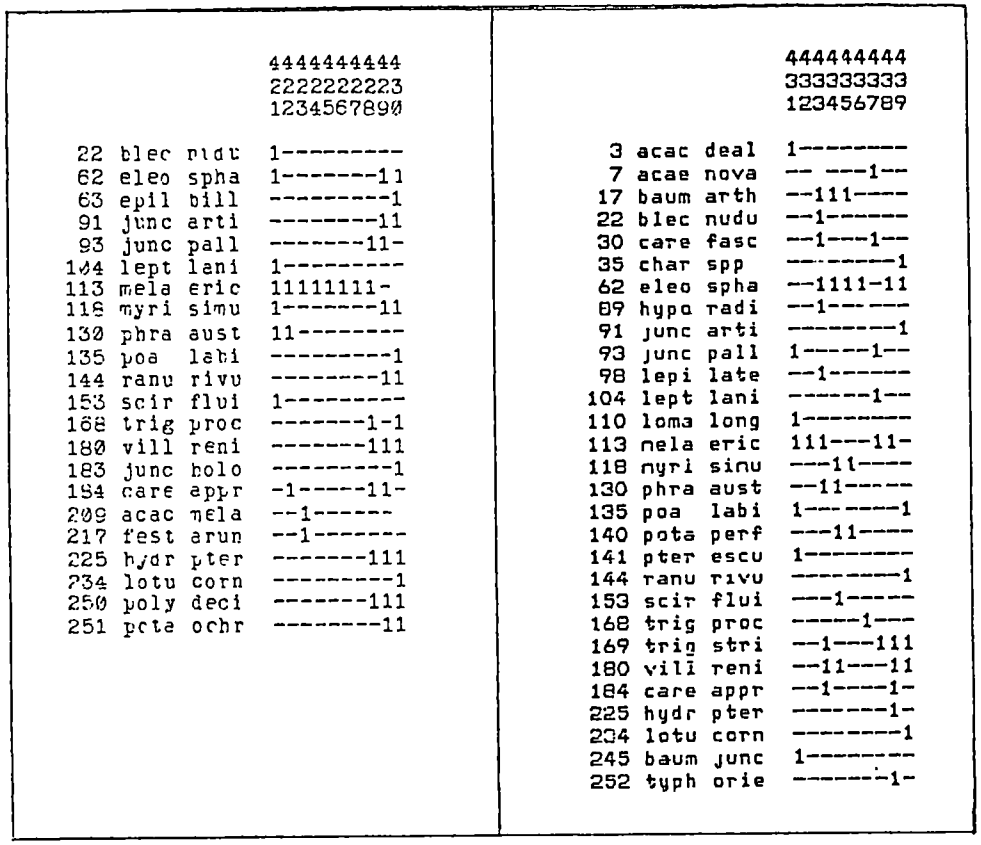
		6666666 0123456
5	acac mucr	1-----1
6	acac vert	111----
13	athe mosc	---1---
16	bank marg	111--1-
20	beye visc	--1----
30	care fasc	--1----
32	cass pube	1------
41	corr refl	-1-----
74	euca vimi	------1
78	hake liss	11-----
80	halo teuc	-1----1
83	hibb ripp	1------
85	hove hete	---1---
89	hypo radi	------1
98	lepi late	----11-
104	lept lani	111-1--
105	lept scop	1---1--
110	loma long	11----1
111	loma tinc	1------
116	micr hexa	---1---
121	note ligu	-11-1--
123	olea argo	------1
160	spyr obov	--11111
163	styl gram	-11----
187	bryo phte	----11-
188	fern fern	---1---

		4444444555555555 3456789012345678 9
5	acac mucr	11111-1-1----1-1-
11	aotu eric	-----111---------
12	astr humi	1----------------
16	bank marg	1-------------1--
20	beye visc	-1-1--111--111-1-
22	blec nudu	----------1------
23	blec wats	----------11----
38	clem micr	1---1-1----------
40	copr hert	1----------------
47	cyat parv	-1--1111-----1-1-
71	euac obli	11---------------
74	euca vimi	------------11-1
76	ghan gran	111----------1---
78	hake liss	11---------------
80	halo teuc	1------1---------
83	hibb ripp	------1----------
98	lepi late	1----------------
104	lept lani	11-111-11-111-111
110	loma long	1----------------
111	loma tinc	1----111--------1
121	note ligu	---------------1-
123	olea argo	-1------1--------
137	poma apet	-11-----1-----11-
186	lich en	1----------------
187	bryo phte	-------1111111---

Transect 21

Transect 22

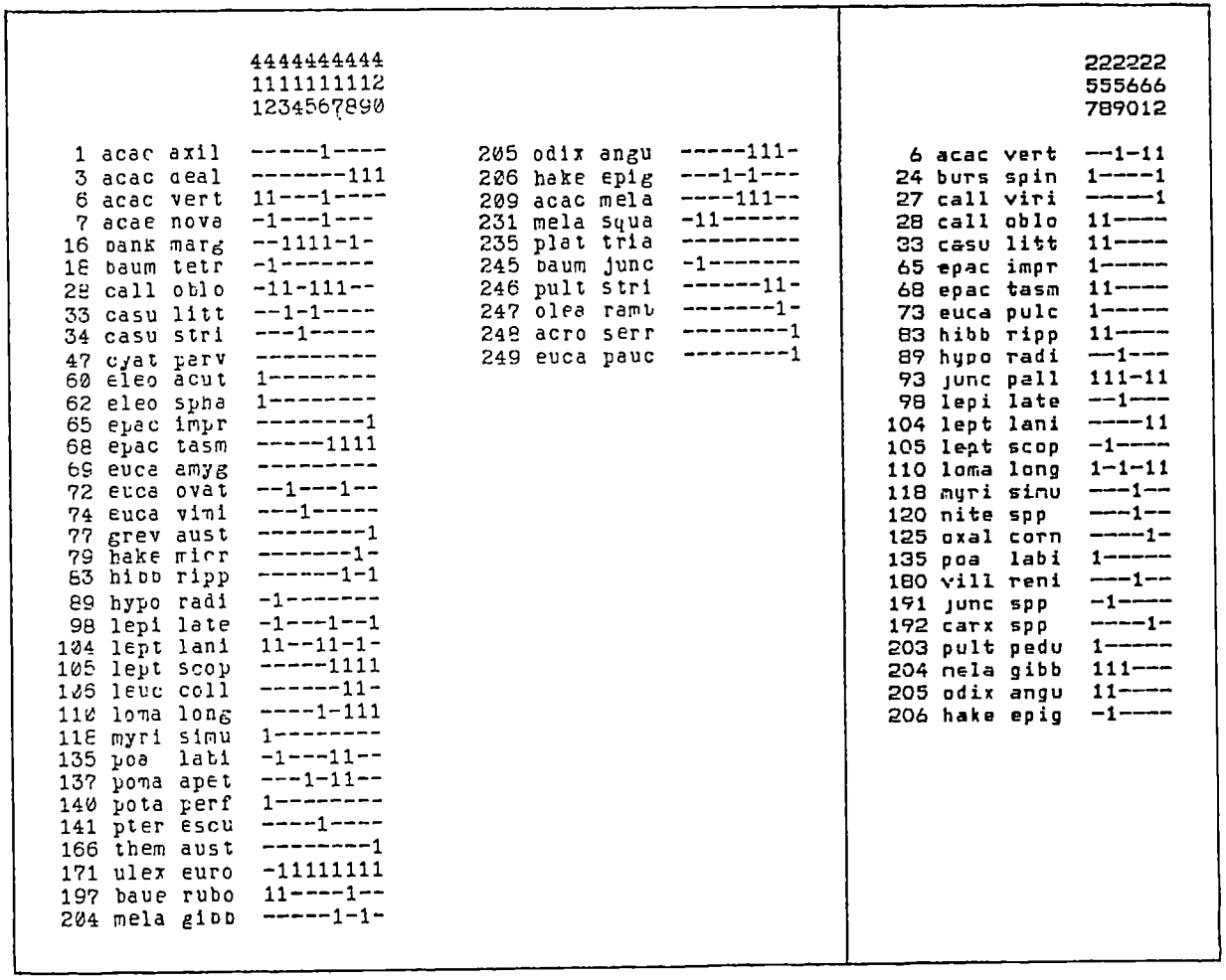
Transect 23



```
                          4444444444
                          2222222223
                          1234567890

 22 blec nudu             1---------
 62 eleo spha             1-------11
 63 epil bill             ---------1
 91 junc arti             --------11
 93 junc pall             -------11-
104 lept lani             1---------
113 mela eric             11111111-
118 myri simu             1-------11
130 phra aust             11--------
135 poa  labi             ---------1
144 ranu rivu             --------11
153 scir flui             1---------
168 trig proc             -------1-1
180 vill reni             -------111
183 junc bolo             ---------1
184 care appr             -1-----11-
209 acac mela             --1------
217 fest arun             --1-------
225 hydr pter             -------111
234 lotu corn             ---------1
250 poly deci             -------111
251 pota ochr             --------11
```

```
                          444444444
                          333333333
                          123456789

  3 acac deal             1--------
  7 acae nova             -- ---1--
 17 baum arth             --111----
 22 blec nudu             --1------
 30 care fasc             --1---1--
 35 char spp              ---------1
 62 eleo spha             --1111-11
 89 hypo radi             --1------
 91 junc arti             --------1
 93 junc pall             1-----1--
 98 lepi late             --1------
104 lept lani             ------1--
110 loma long             1--------
113 mela eric             111---11-
118 myri sinu             ---11----
130 phra aust             --11-----
135 poa  labi             1-------1
140 pota perf             ---11----
141 pter escu             1--------
144 ranu rivu             ---------1
153 scir flui             ---1-----
168 trig proc             -----1---
169 trig stri             --1---111
180 vill reni             --11---11
184 care appr             --1----1-
225 hydr pter             -------1-
234 lotu corn             --------1
245 baum junc             1--------
252 typh orie             -------1-
```

Apsley River Transect 24 Transect 25

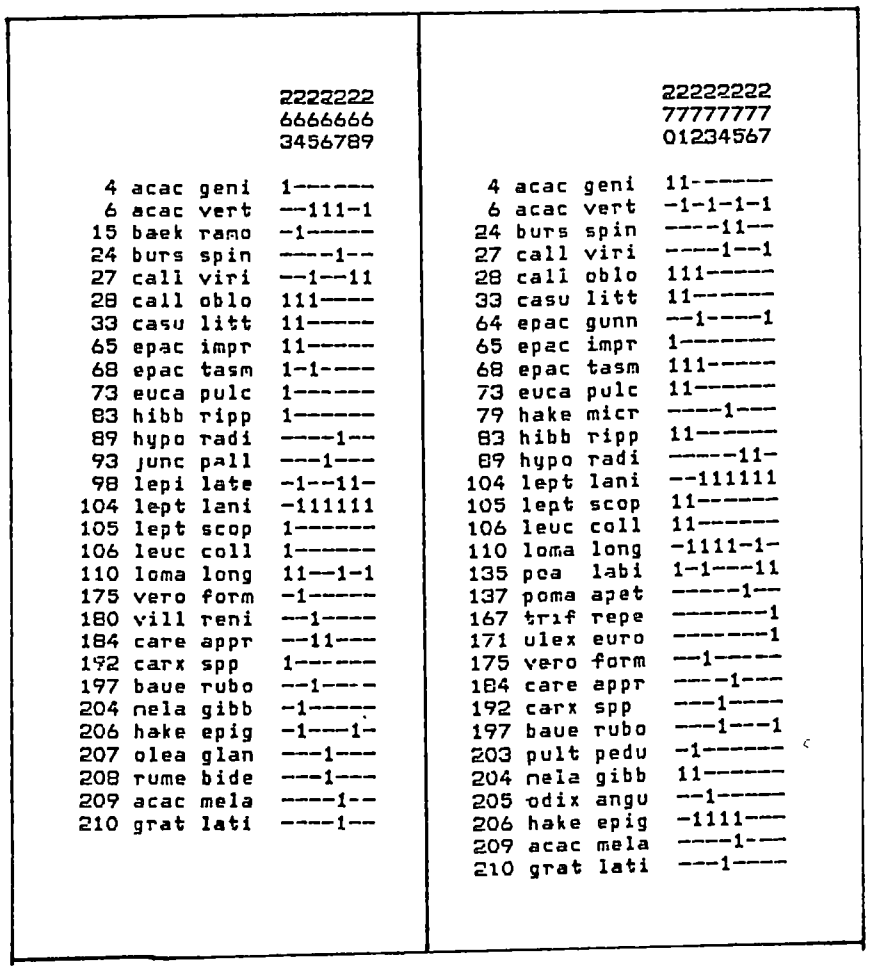


```
                  4444444444
                  1111111112
                  1234567890

  1 acac axil     -----1----
  3 acac deal     -------111
  6 acac vert     11---1----
  7 acae nova     -1---1---
 16 bank marg     --1111-1-
 18 baum tetr     -1-------
 22 call oblo     -11-111--
 33 casu litt     --1-1----
 34 casu stri     ---1-----
 47 cyat parv     ---------
 60 eleo acut     1--------
 62 eleo spha     1--------
 65 epac impr     --------1
 68 epac tasm     -----1111
 69 euca amyg     ---------
 72 euca ovat     --1---1--
 74 euca vimi     ---1-----
 77 grev aust     --------1
 79 hake micr     -------1-
 83 hibb ripp     ------1-1
 89 hypo radi     -1-------
 98 lepi late     -1---1--1
104 lept lani     11--11-1-
105 lept scop     -----1111
106 leuc coll     ------11-
110 loma long     ----1-111
118 myri simu     1--------
135 poa  labi     -1---11--
137 poma apet     ---1-11--
140 pota perf     1--------
141 pter escu     ----1----
166 them aust     --------1
171 ulex euro     -11111111
197 baue rubo     11----1--
204 mela gibb     -----1-1-
205 odix angu     -----111-
206 hake epig     ---1-1---
209 acac mela     ----111--
231 mela squa     -11------
235 plat tria     ---------
245 baum junc     -1-------
246 pult stri     ------11-
247 olea ramu     -------1-
248 acro serr     --------1
249 euca pauc     --------1
```

Transect 26

```
                  222222
                  555666
                  789012

  6 acac vert     --1-11
 24 burs spin     1----1
 27 call viri     -----1
 28 call oblo     11----
 33 casu litt     11----
 65 epac impr     1-----
 68 epac tasm     11----
 73 euca pulc     1-----
 83 hibb ripp     11----
 89 hypo radi     --1---
 93 junc pall     111-11
 98 lepi late     --1---
104 lept lani     ----11
105 lept scop     -1----
110 loma long     1-1-11
118 myri simu     ---1--
120 nite spp      ---1--
125 oxal corn     ----1-
135 poa  labi     1-----
180 vill reni     ---1--
191 junc spp      -1----
192 carx spp      ----1-
203 pult pedu     1-----
204 mela gibb     111---
205 odix angu     11----
206 hake epig     -1----
```

Transect 27

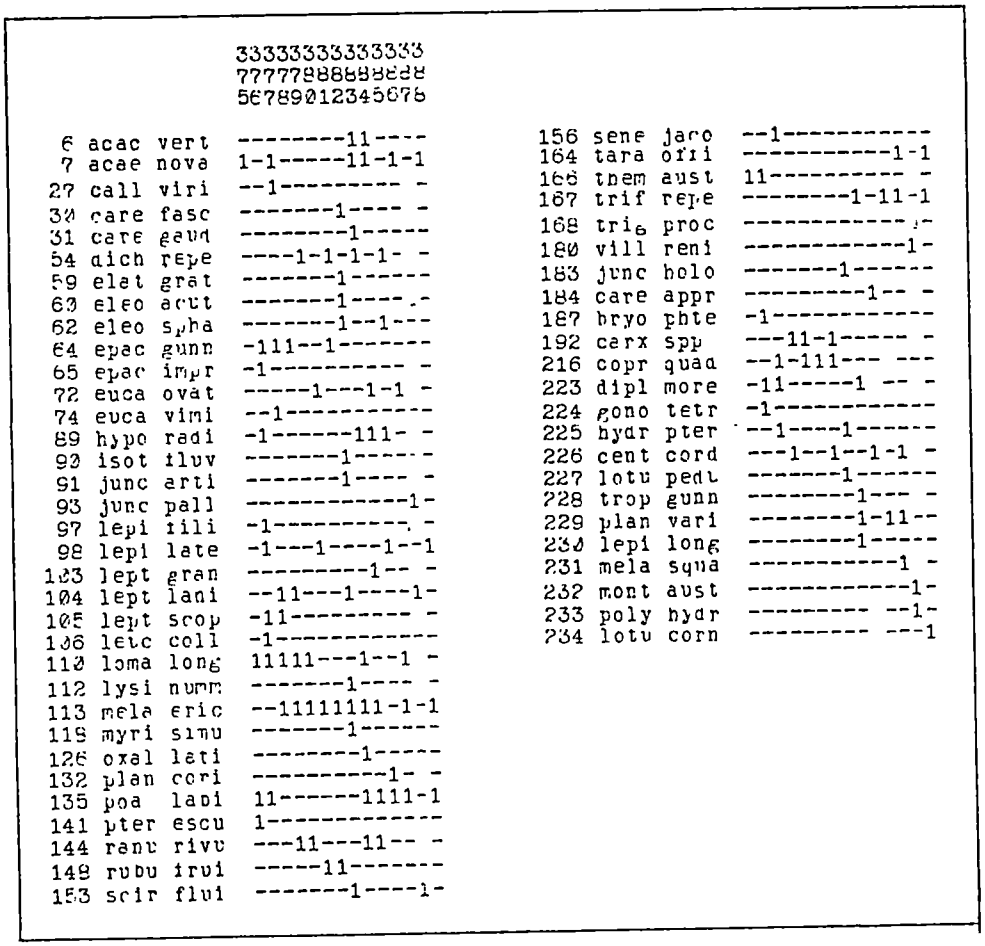


			2222222 6666666 3456789
4	acac	geni	1------
6	acac	vert	--111-1
15	baek	ramo	-1-----
24	burs	spin	----1--
27	call	viri	--1--11
28	call	oblo	111----
33	casu	litt	11-----
65	epac	impr	11-----
68	epac	tasm	1-1----
73	euca	pulc	1------
83	hibb	ripp	1------
89	hypo	radi	----1--
93	junc	pall	---1---
98	lepi	late	-1--11-
104	lept	lani	-111111
105	lept	scop	1------
106	leuc	coll	1------
110	loma	long	11--1-1
175	vero	form	-1-----
180	vill	reni	--1----
184	care	appr	--11---
192	carx	spp	1------
197	baue	rubo	--1----
204	nela	gibb	-1-----
206	hake	epig	-1---1-
207	olea	glan	---1---
208	rume	bide	---1---
209	acac	mela	----1--
210	grat	lati	----1--

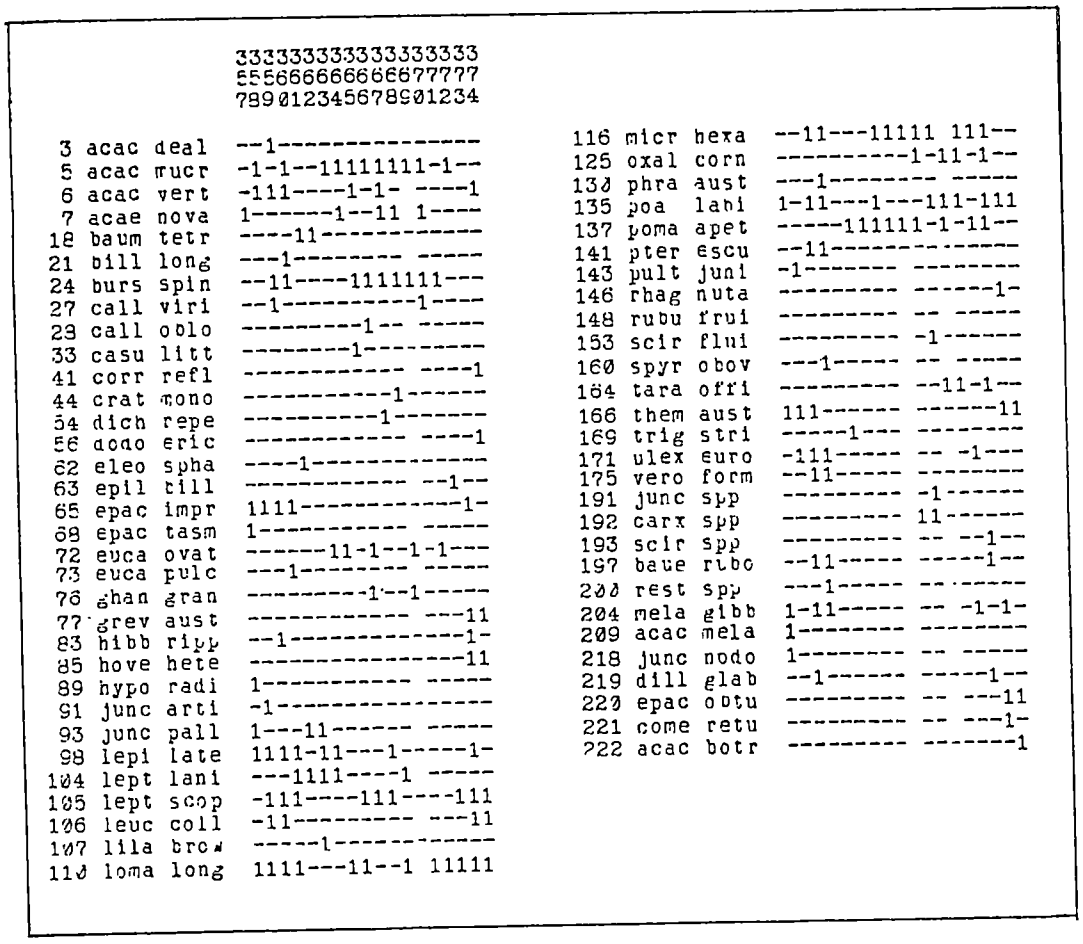
			22222222 77777777 01234567
4	acac	geni	11------
6	acac	vert	-1-1-1-1
24	burs	spin	----11--
27	call	viri	----1--1
28	call	oblo	111-----
33	casu	litt	11------
64	epac	gunn	--1----1
65	epac	impr	1-------
68	epac	tasm	111-----
73	euca	pulc	11------
79	hake	micr	----1---
83	hibb	ripp	11------
89	hypo	radi	-----11-
104	lept	lani	--111111
105	lept	scop	11------
106	leuc	coll	11------
110	loma	long	-1111-1-
135	poa	labi	1-1---11
137	poma	apet	-----1--
167	trif	repe	-------1
171	ulex	euro	-------1
175	vero	form	--1-----
184	care	appr	----1---
192	carx	spp	---1----
197	baue	rubo	---1---1
203	pult	pedu	-1------
204	nela	gibb	11------
205	odix	angu	--1-----
206	hake	epig	-1111---
209	acac	mela	----1---
210	grat	lati	---1----

Transect 28

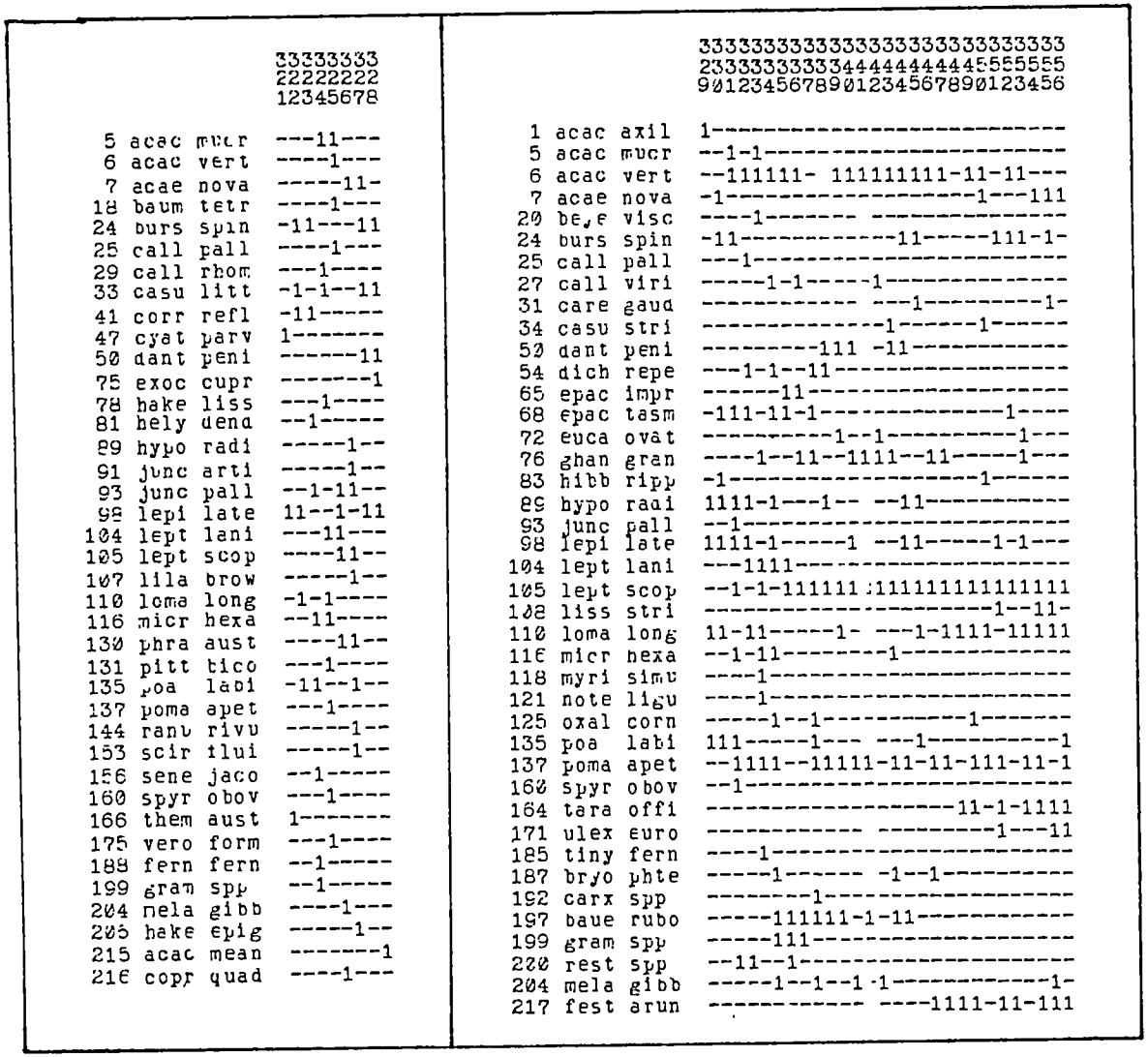
Transect 29


33333333333333
77777888888888
56789012345678
6 acac vert --------11----
7 acae nova 1-1-----11-1-1
27 call viri --1--------- -
30 care fasc -------1---- -
31 care geyd --------1-----
54 dich repe ----1-1-1-1- -
59 elat grat -------1------
60 eleo acut -------1---- -
62 eleo sp ha -------1--1---
64 epac gunn -111--1-------
65 epac impr -1---------- -
72 euca ovat -----1---1-1 -
74 euca vimi --1----------
89 hypo radi -1------111- -
90 isot fluv -------1------
91 junc arti -------1---- -
93 junc pall ----------1-
97 lepi tili -1---------- -
98 lepi late -1---1----1--1
103 lept gran ---------1-- -
104 lept lani --11---1----1-
105 lept scop -11--------- -
106 letc coll -1----------
110 loma long 11111---1--1 -
112 lysi numm -------1---- -
113 mela eric --11111111-1-1
119 myri simu -------1------
126 oxal lati --------1-----
132 plan cori ----------1- -
135 poa lani 11------1111-1
141 pter escu 1----------
144 ranu rivu ---11---11-- -
148 rubu trui -----11-------
153 scir flui -------1----1-
156 sene jaco --1----------
164 tara offi ----------1-1
166 them aust 11---------- -
167 trif repe --------1-11-1
168 trig proc ---------- -
180 vill reni ----------1-
183 junc holo -------1------
184 care appr ---------1-- -
187 bryo phte -1----------
192 carx spp ---11-1----- -
216 copr quad --1-111--- ---
223 dipl more -11-----1 -- -
224 gono tetr -1----------
225 hydr pter --1----1------
226 cent cord ---1--1--1-1 -
227 lotu pedu -------1------
228 trop gunn --------1--- -
229 plan vari --------1-11--
230 lepi long --------1-----
231 mela squa ----------1 -
232 mont aust ----------1-
233 poly hydr --------- --1-
234 lotu corn --------- ---1

Transect 30

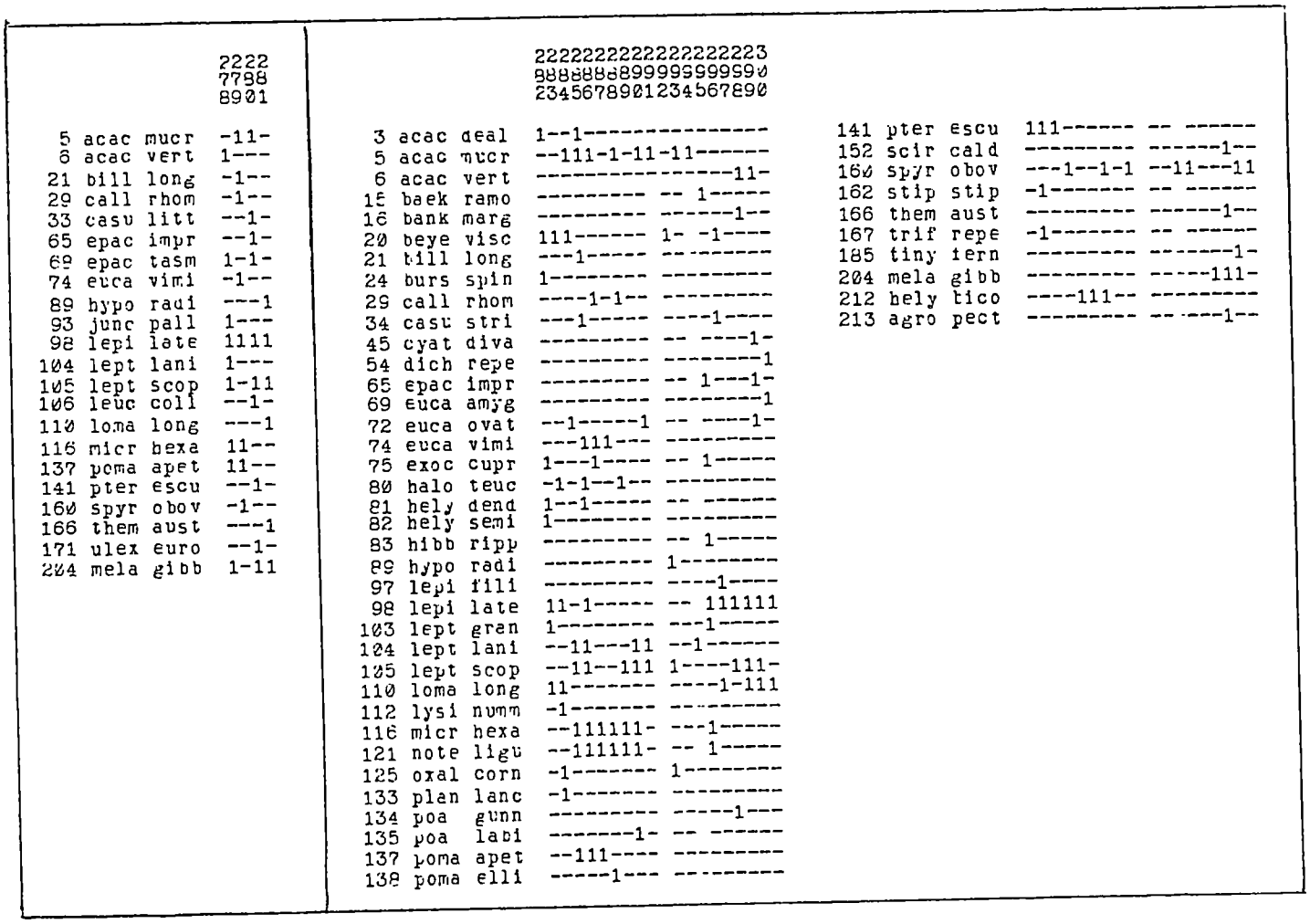

333333333333333333
555666666666677777
789012345678901234
3 acac deal --1----------
5 acac mucr -1-1--11111111-1--
6 acac vert -111----1-1- ----1
7 acae nova 1------1--11 1----
18 baum tetr ----11----------
21 bill long ---1-------- -----
24 burs spin --11----1111111---
27 call viri --1----------1----
28 call oblo ---------1-- -----
33 casu litt --------1---------
41 corr refl ---------- ----1
44 crat mono ----------1------
54 dich repe ----------1-------
56 dodo eric ---------- ----1
62 eleo spha ----1----------
63 epil till ---------- --1--
65 epac impr 1111----------1-
68 epac tasm 1---------- -----
72 euca ovat ------11-1--1-1---
73 euca pulc ---1-------- -----
76 ghan gran ---------1--1-----
77 grev aust ---------- ---11
83 hibb ripp --1----------1-
85 hove hete ----------11
89 hypo radi 1---------- -----
91 junc arti -1----------
93 junc pall 1---11------ -----
98 lepi late 1111-11---1-----1-
104 lept lani ---1111----1 -----
105 lept scop -111----111----111
106 leuc coll -11--------- ---11
107 lila brow -----1----------
110 loma long 1111---11--1 11111
116 micr hexa --11---11111 111--
125 oxal corn ----------1-11-1--
130 phra aust ---1-------- -----
135 poa lani 1-11---1---111-111
137 poma apet -----111111-1-11--
141 pter escu --11---------.-----
143 pult juni -1------- --------
146 rhag muta --------- ------1-
148 rubu frui --------- -- -----
153 scir flui --------- -1------
160 spyr obov ---1----- -- -----
164 tara offi --------- --11-1--
166 them aust 111------ ------11
169 trig stri -----1--- --------
171 ulex euro -111----- -- -1---
175 vero form --11----- --------
191 junc spp --------- -1------
192 carx spp --------- 11------
193 scir spp --------- -- --1--
197 baue rubo --11----- -----1--
200 rest spp ---1----- --.-----
204 mela gibb 1-11----- -- -1-1-
209 acac mela 1-------- --------
218 junc nodo 1-------- -- -----
219 dill glab --1------ -----1--
220 epac obtu --------- -- ---11
221 come retu --------- -- ---1-
222 acac botr --------- -------1

Transect 31



Transect 32

Transect 33



Transect 34

Transect 35

```
                    3333333333
                    2222223001
                    1234567890

  5 acac mucr       ---1-11---
  6 acac vert       1--------
 15 baek ramo       ---1------
 16 bank marg       ----1-----
 21 bill long       --------1-
 27 call viri       -------111
 28 call oblo       ---------1
 29 call rhom       --------1-
 34 casu stri       1---1--111
 45 cyat diva       1-1-------
 47 cyat parv       --------1-
 65 epac impr       -------111
 68 epac tasm       ---1------
 69 euca amyg       -11-------
 74 euca vimi       ---------1
 79 hake micr       -------1-1
 83 hibb ripp       11------1-
 97 lepi tili       ---1------
 98 lepi late       11111----
104 lept lani       ---11111--
105 lept scop       ---1------
110 loma long       1---------
111 loma tinc       1--------
116 micr hexa       1111------
121 note ligu       -----1--11
135 poa  labi       --1------1
160 spyr obov       ---1---111
162 stip stip       1---------
175 vero form       --------11
187 bryo phte       -------11-
192 carx spp        ---------1
214 eris pedu       1-1-------
215 acac mean       --------1
```

Transect 36

```
                    33344444444444
                    99900000000001
                    78921234567890

  1 acac axil       ------1-------
  2 acac rice       -------1-1-- 1
  4 acac geni       1------------
  5 acac mucr       --111-1111----
  6 acac vert       ----1------- -
 12 astr humi       --1------ --1-
 16 bank marg       111------ ----
 24 burs spin       --------- --1-
 25 call pall       ---111--1 1- -
 29 call rhom       -11------ --11
 33 casu litt       -1--1-111 -1 -
 41 corr refl       --------- ---1
 65 epac impr       1-1--1111 ---1
 71 euac obli       11------- ----
 74 euca vimi       --1------ -- -
 79 hake micr       ----1111- 1-1-
 83 hibb ripp       1-------- ----
 98 lepi late       --1-1---- ----
 99 lepi line       --------1 -1 -
103 lept gran       1-------1 ----
104 lept lani       ------1-1 ----
105 lept scop       1-1-111-- 1- -
111 loma tinc       1-----1-- ----
116 micr hexa       -1-11--11 -- -
117 myri pedu       --------- 1---
135 poa  labi       --------- -1 1
137 pome apet       --------- --1-
145 rhag baca       --------- --1-
152 scir cald       -----1--- ----
153 scir flui       --------- 1- -
160 spyr obov       1------1- --1-
168 trig proc       -----11-- -- -
187 bryo phte       -1------- -- -
191 junc spp        --------1 ----
192 carx spp        1-------1 -- -
197 baue rubo       ------1-- ----

200 rest spp        ------111 ----
206 hake epig       ------1-- ----
240 rest moni       -----1--- -- -
241 boro pilo       -------11 111-
242 spyr obco       --------1 -- -
243 lept ripa       --------1 11--
244 pime pauc       --------- ---1
```

Transect 37

```
                  33333333
                  89999999
                  90123456

  5 acac mucr     -11-1111
  6 acac vert     ---1---1
 15 baek rano     -1---11-
 16 bank marg     -1-1--11
 27 call viri     --1-----
 29 call rhom     1-------
 33 casu litt     11-11---
 46 cyat juni     1-------
 65 epac impr     -1---1--
 68 epac tasm     ---1----
 74 euca vimi     11-----1
 75 exoc cupr     -------1
 83 hibb ripp     1-111111
 98 lepi late     --11111-
 99 lepi line     1----1--
104 lept lani     -1111---
105 lept scop     -1111111
111 loma tinc     -----11-
116 micr hexa     -1111111
137 poma apet     --11----
141 pter escu     ----1111
143 pult juni     ---1-1--
153 scir flui     ---1----
160 spyr obov     1-111111
168 trig proc     ---1----
197 baue rubo     ---1----
206 hake epig     -111----
211 pheb squa     ----1---
235 plat tria     1-------
236 poma pili     1----111
237 zier arbo     -1------
238 stip aphy     ---1----
239 cryp amar     ------11
```

Transect 38

```
                  333333
                  111112
                  567890

  5 acac mucr     11--11
 16 bank marg     ----11
 19 bedf seli     1-----
 21 bill long     1-----
 41 corr refl     -----1
 43 cras sieb     ----1-
 46 cyat juni     -----1
 68 epac tasm     -----1
 79 hake micr     ----1-
 80 halo teuc     ---111
 82 hely semi     ---1-
 98 lepi late     11-1-1
103 lept gran     ----11
104 lept lani     --1---
111 loma tinc     ----11
116 micr hexa     11111-
131 pitt bico     -----1
160 spyr obov     -11---
196 spyr parv     -----1
211 pheb squa     -1----
```

Transect 39

```
                  3333
                  1111
                  1234

  5 acac mucr     -11-
 13 athe mosc     --11
 21 bill long     --1-
 43 cras sieb     1---
 45 cyat diva     1---
 72 euca ovat     1---
 80 halo teuc     -1--
 98 lepi late     -11-
104 lept lani     -1--
111 loma tinc     -1--
116 micr hexa     1111
131 pitt bico     --11
137 poma apet     ---1
160 spyr obov     11--
187 bryo phte     -1-1
```

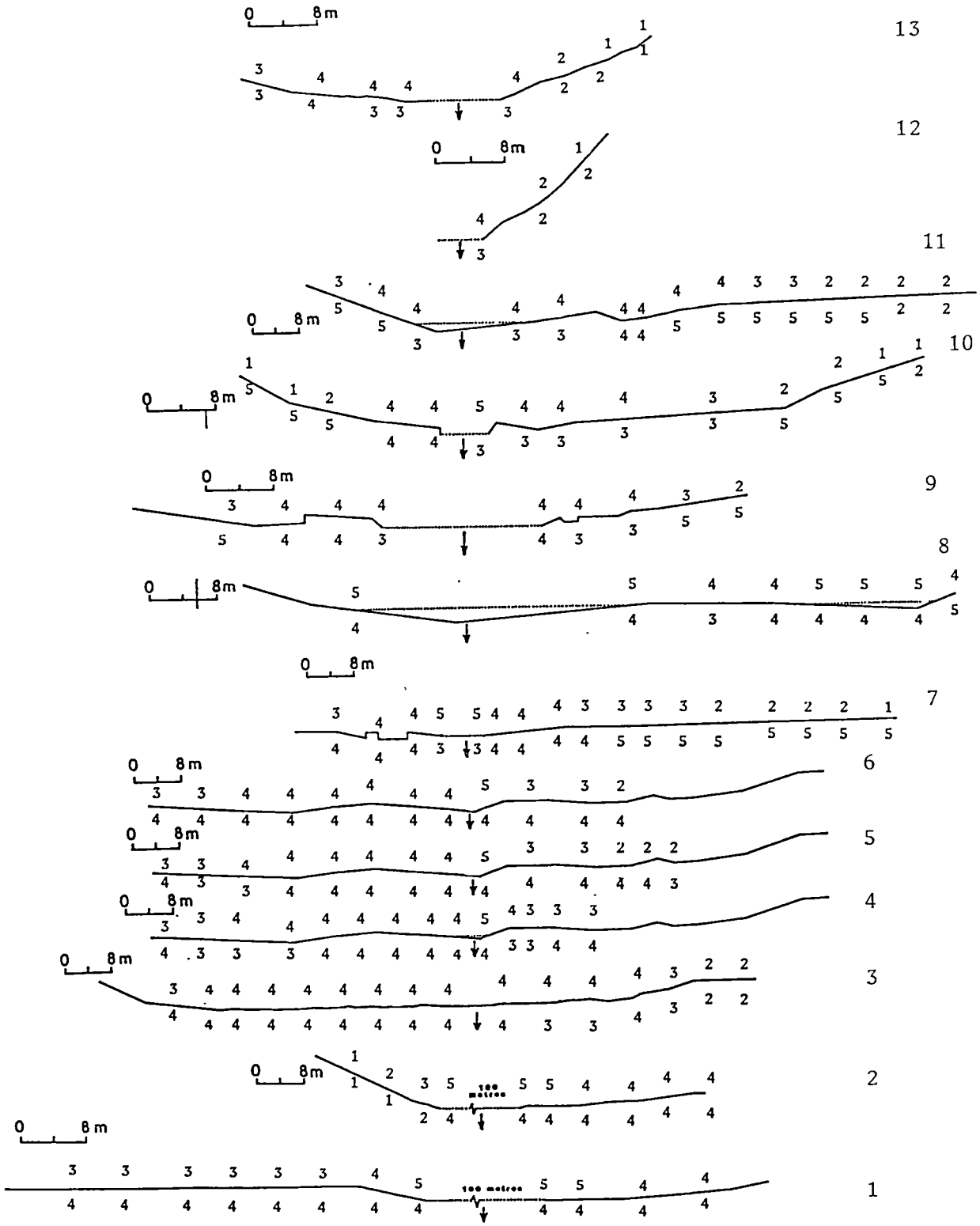
Transect 40

APPENDIX 6

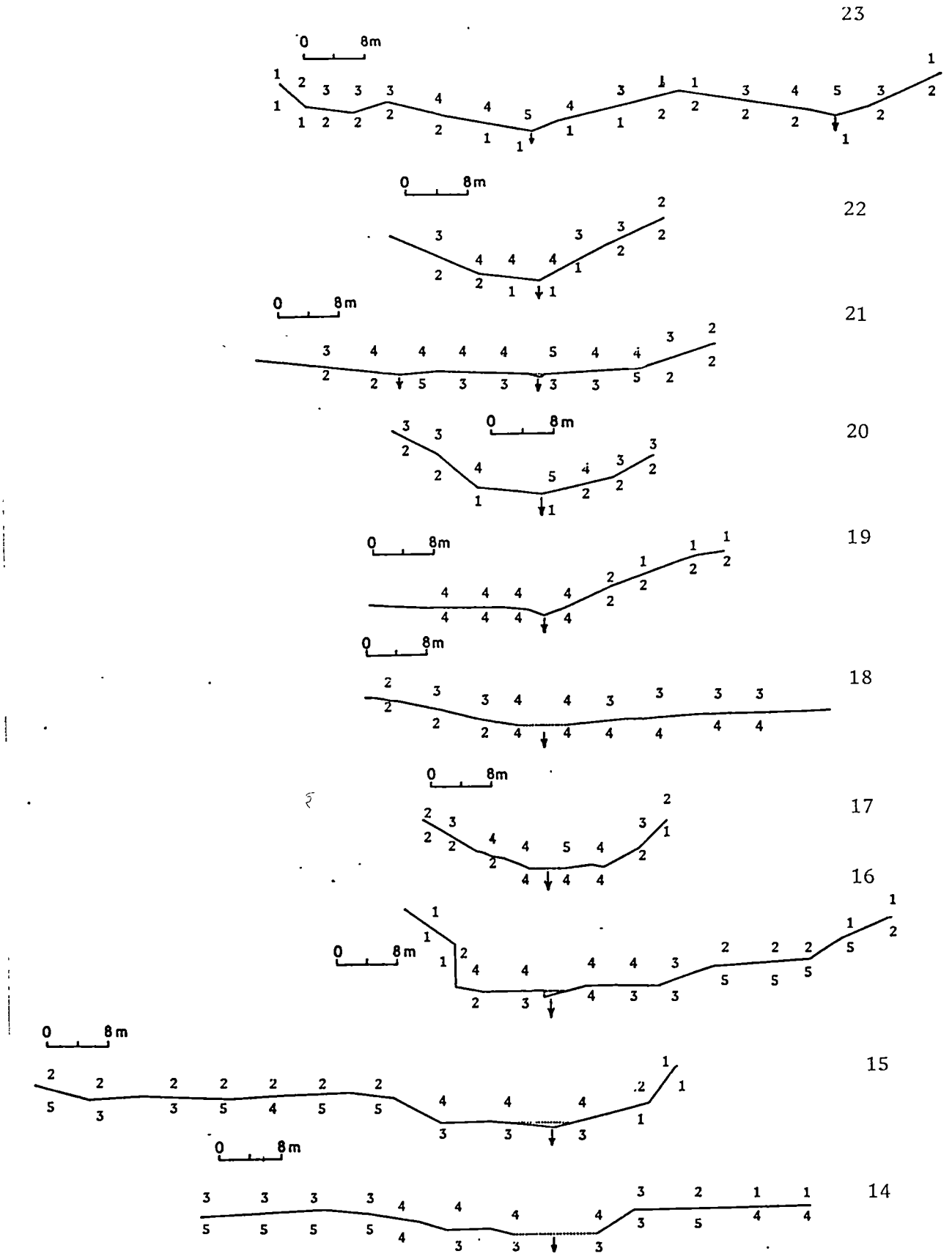
Flow frequency and substrate data for each of the 439 quadrats sampled along the Swan and Apsley Rivers.
The figure above the profile is flow frequency, and the figure below the profile is substrate:

Below
1 = solid rock
2 = boulders
3 = cobble & pebble (unconsolidated)
4 = sand & silt
5 = cobble & pebble (consolidated)

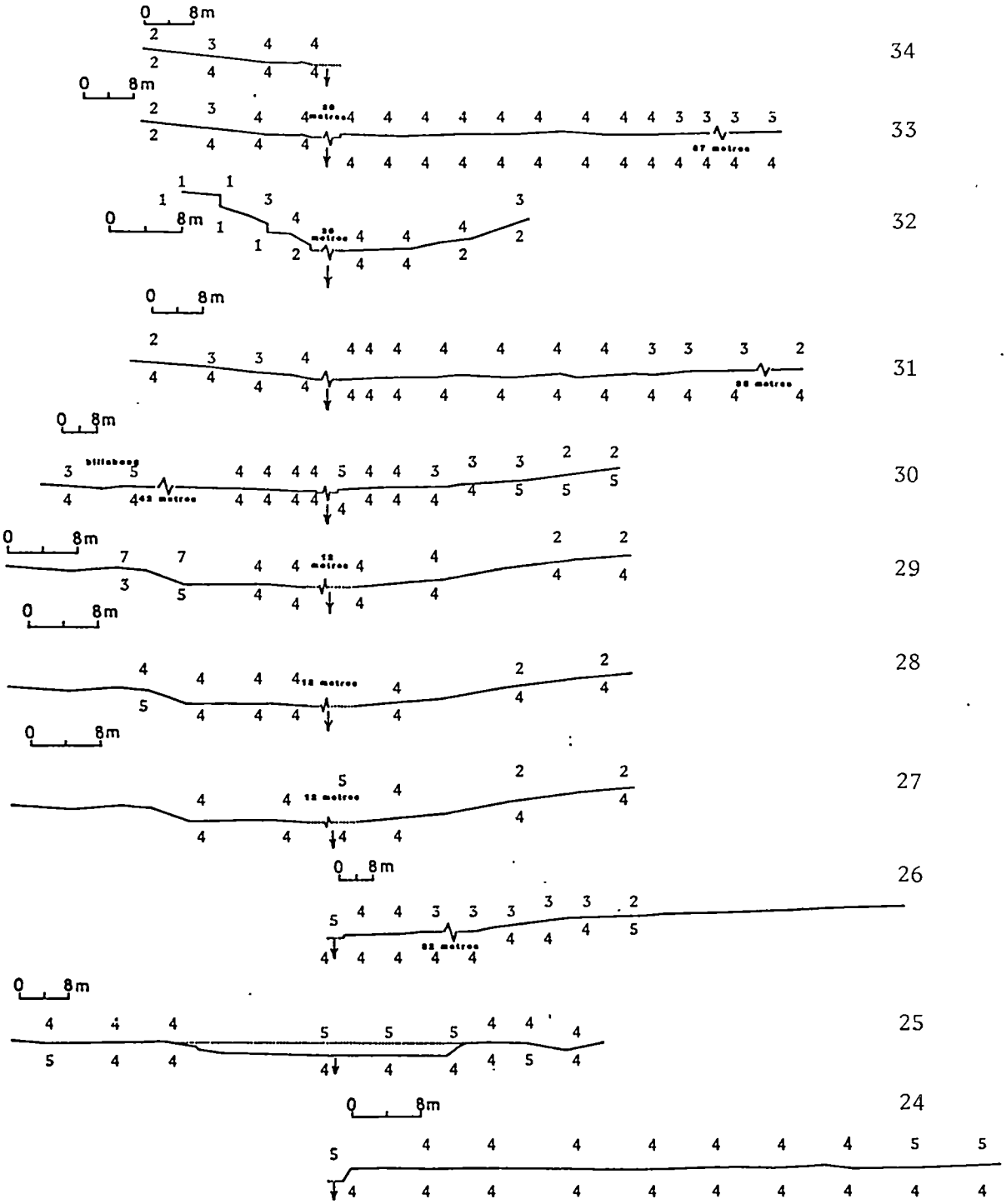
Above
1 = 1 in 22 month to 1 in 10 year flow
2 = 1 in 12 month to 1 in 22 month flow
3 = 1 in 6 month to 1 in 12 month flow
4 = permanent to 1 in 6 month flow
5 = permanent water



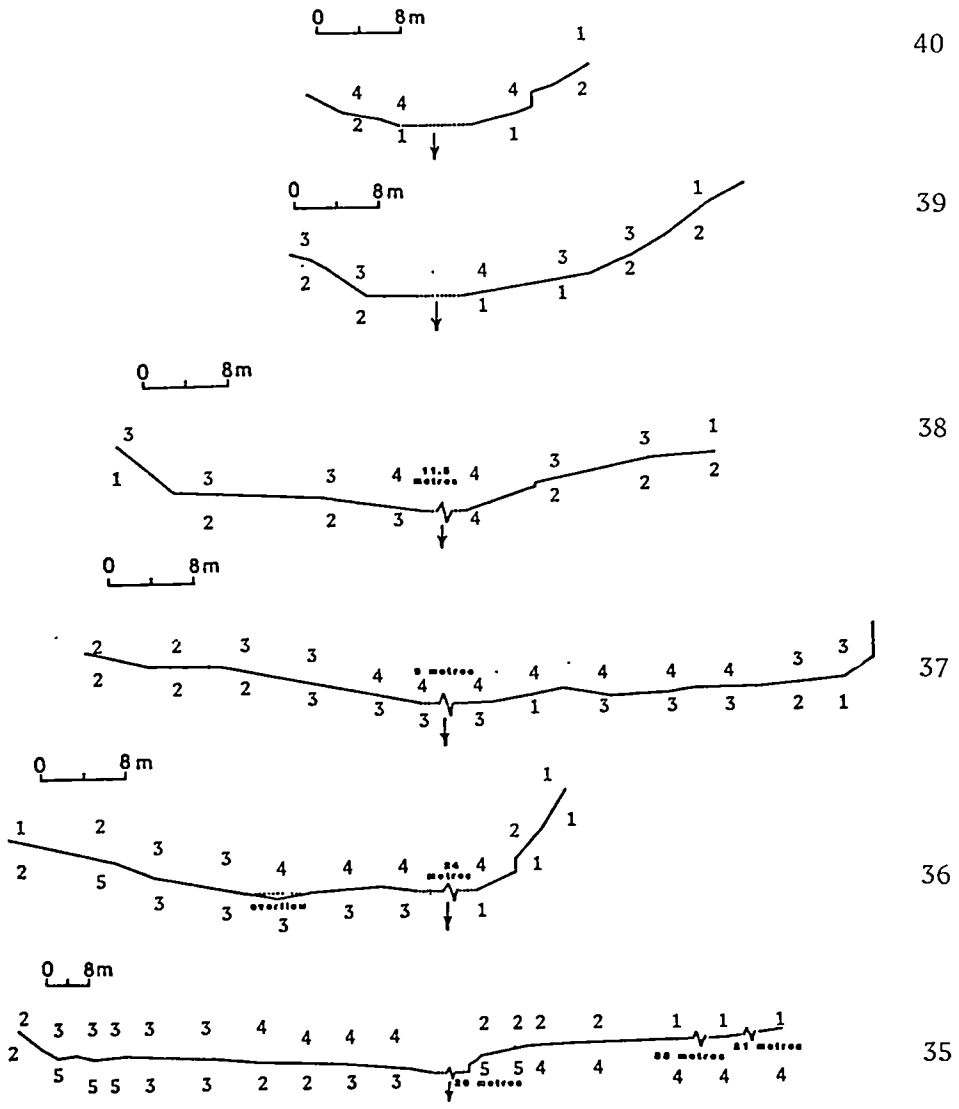
Swan River


23
0 8m
22
0 8m
21
0 8m
20
0 8m
19
0 8m
0 8m
18
0 8m
17
16
0 8m
0 8m
15
0 8m
14

Swan River



Apsley River



Apsley River

APPENDIX 7

List of species sampled in the geographical survey of riverine aquatic plants

1 Centella cordifolia
2 Villarsia reniformis
3 V. exaltata
4 Hydrocotyle javanica
5 Eleocharis sphacelata
6 E acuta
7 Triglochin striata
8 T. procera
9 Lilaeopsis brownii
10 Zostera muelleri
11 Myriophyllum amphibium
12 Cotula coronopifolia
13 Ranunculus rivularis
14 Nitella sp.
15 Myriophyllum salsugineum
16 Phragmites australis
17 Rumex bidens
18 Callitriche stagnalis
19 Schoenus fluitans
20 Myriophyllum pedunculatum
21 Typha orientalis
22 Gratiola nana
23 Potamogeton perfoliatus
24 P. tricarinatus
25 Chara sp.
26 Potamogeton perfoliatus
27 P. pectinatus
28 Haloragis brownii
29 Rorippa nasturtiumaquaticum
30 Ruppia megacarpa
31 Ruppia polycarpa
32 Claytonia australasica
33 Lemna minor
34 Utricularia australis
35 Nymphoides exigua
36 Lepilaena sp.
37 Ranunculus trichophyllous
38 Scirpus fluitans
39 Isotoma fluviatilis
40 Elodea canadensis
41 Centipeda minima
42 Ranunculus inundatus
43 Elatine gratioloides
44 Rorippa microphylla
45 Crassula helmsii
46 Potamogeton australiensis
47 Hydrocotyle muscosa
48 Apium australe
49 Hydrocotyle pterocarpa
50 Myriophyllum sp.
51 Juncus articulatus
52 Myriophyllum simulans
53 Typha domingensis
54 Polygonum hydropiper
55 Myriophyllum varifolium
56 Caltha phylloptera
57 Gunnera cordifolia
58 Ranunculus triplodontus
59 Lemna trisulca
60 Vallisneria gigantea
61 Azolla filiculoides
62 Juncus pallidus
63 Utricularia dichotoma
64 Alisma plantago-aquatica
65 Wolffia australiana
66 Nymphaea sp.